J&E Hall International

HallScrew HSO 2000 Series

Open Drive Single Screw Compressors

HSO 2024, HSO 2028, HSO 2031 and HSO 2035

Manufactured after 06/03

Installation, Operation and Maintenance Manual

Safety

In common with most other forms of mechanical and electrical equipment, there are a number of potential hazards associated with operating and servicing refrigeration plant.

In writing this instruction manual every emphasis has been given to safe methods of working. These safety instructions are intended to draw attention to the potential hazards that could be encountered during installing, operating and maintaining the plant. At the same time, it should be emphasised that these notes are not exhaustive, and are principally intended to draw attention to the most important points; where necessary, reference is made to other parts of the manual.

Please note that the installer is responsible for the correct installation of equipment, and on completion, the owner and/or user are responsible for safe operation and maintenance.

Personnel Permitted to Install, Commission and Maintain the Plant

It is essential that only authorised and competent personnel are allowed to install, commission and maintain the plant. A permit to work system should be introduced before commissioning begins, and should be rigorously enforced thereafter.

Any person rendering assistance or under training must be supervised by the authorised competent person who has responsibility for safety.

Personnel must be familiar with the plant's construction, operation and the hazards involved. **All** personnel should make a thorough study of these instructions before undertaking installation, commissioning, maintenance or repair procedures.

⚠ WARNING

A minimum of two personnel should always be present when working on ammonia refrigeration plant.

Mechanical

Refrigeration compressors manufactured and/or supplied by J & E Hall International must be operated within their design parameters, and should never be used as vacuum pumps or for compressing air.

Personnel must not start the plant until they have taken steps to verify the following:

- Guards on couplings, belt drives and fans are in place, and other personnel are not in positions that might be hazardous when the plant is in operation.
- The compressor discharge stop valve is fully open.

Parts of the plant, specifically the compressor, drive motor and discharge line, are liable to be at temperatures high enough to cause a burn. A 'cold' burn can result from accidentally touching any part of the plant containing oil at low temperature, or subcooled liquid refrigerant.

Personnel who stop the plant must be aware of the potential hazard if pipeline stop valves are closed in such a manner as to trap cold liquid refrigerant between valves. If this should accidentally occur, rising ambient temperature will cause the liquid to expand and eventually fracture the pipe or valves, etc.

Stop valves should be opened slowly to begin with and by a small amount, say half a turn, before the valve is fully opened. This procedure allows system temperatures and pressures to equalise gradually, so reducing the risk of physical and/or thermal shock which might cause damage.

Examination of Pressure Systems

Within the United Kingdom, statutory regulations require the user to prepare a 'written scheme of examination' to cover all parts of the plant subject to pressure. It is a requirement that the scheme be introduced before the plant is put into operation for the first time. If the plant is modified, the written scheme of examination must be reviewed and updated to incorporate these modifications.

Noise Hazard

The majority of noise emanating from refrigeration plant is produced by the compressor(s), pump(s) and fan(s) and the motors which drive them. While short term exposure to the typical average noise level which might be encountered is unlikely to be detrimental to health, ear defenders should be worn by those personnel who have to work near major sources of noise. The type of ear defenders worn must not compromise the wearing of other essential safety clothing, for example, goggles or a respirator.

Electrical

Electrical wiring must be sized and installed to such a standard as to meet the requirements of the national or local codes pertaining to the area in which the installation is taking place.

The electrical power used in this equipment is at a voltage high enough to endanger life. Before undertaking maintenance or repair procedures on electrical equipment, personnel must isolate equipment from the electrical supply and test to verify that isolation is complete. Precautions must be taken to prevent circuits being inadvertently energised, for example, withdraw the mains fuses, or, if this is not practicable, disconnect the equipment from the supply before work commences.

If the supply cannot be disconnected or must remain connected to permit functional testing, fault diagnosis and repair should only be undertaken by persons who are aware of the hazard and who have taken adequate precautions to avoid direct contact with dangerous voltages.

If electrical equipment overheats or a fault occurs, it must be disconnected from the supply and allowed to cool. Overheating may damage the insulation system, cables, mouldings, gaskets and seals. The materials used in these components may contain complex organic compounds which, when degraded by heat or electrical action, produce chemical compounds in gaseous, liquid or solid forms. Many of these gaseous and liquid product compounds are highly flammable and toxic.

If it is necessary to extinguish a fire in electrical equipment, follow the advice given in the Fire Precautions Act 1971, 'Guide to Fire Precautions in Existing Places of Work that require a Fire Certificate' available from HMSO. Do not approach the equipment until the fire has been extinguished and the equipment is cool.

Lubricating Oils

Refrigeration oils are unlikely to present any significant health and safety hazard provided they are used properly, and good standards of industrial and personal hygiene are maintained. The following general precautions are recommended:

- Avoid unnecessary handling of oily components. Use of a barrier cream is recommended.
- Oils are potentially flammable and should be stored and handled with this in mind. Rags or disposable 'wipes' used for cleaning purposes should be kept well away from naked flames and disposed of properly.
- Oil contained in the compressor lubrication system, oil separator, oil filter etc, will remain hot enough to cause burns for some time after the system has been shut down. If it is necessary to open the system soon after the compressor has stopped, to change the oil filter for example, always allow long enough for the oil to cool down so that the oil which is likely to escape is cool enough not to be a danger (less than 35 °C is recommended).

Ammonia Refrigerant 717

Refrigeration systems contain liquid and vapour under pressure; personnel should be aware of this fact at all times. Suitable precautions must be taken to guard against the pressure hazard when opening any part of the system.

Opening up part of the primary refrigeration circuit will necessitate the loss of a certain amount of refrigerant to atmosphere. It is essential to restrict the amount which escapes to a minimum by pumping over and isolating the charge in another part of the system.

Where lubricating oil may be present, when changing the oil filter element for example, caution must be exercised as the oil will contain a certain amount of refrigerant which will be released when subjected to atmospheric conditions.

Refrigerant and lubricating oil, especially liquid refrigerant at low temperature, can cause freezing injuries similar to a burn if allowed to come into contact with the eyes or skin. Suitable protective clothing, gloves, goggles etc. must be worn when opening pipes or vessels which may contain liquid.

Ammonia, refrigerant R717, is a colourless gas with a very powerful characteristic smell which is so pungent that it is unpleasant at concentrations too low to be considered dangerous.

Ammonia has inherent material and physiological hazards. A limited range of ammonia/air mixtures (16 % to 27 % ammonia by volume) can be ignited by a naked flame and an explosion may result. While ammonia is not a cumulative poison, exposure will cause chemical burns and can destroy body tissue. Because of ammonia's high affinity with water, moist areas of the skin, breathing passages and the eyes, are areas particularly susceptible to damage.

Maintenance procedures must not be carried out unless adequate fan assisted ventilation has been provided to avoid any risk of explosion or physiological harm. Naked flame must not be permitted in the area. Personnel carrying out maintenance procedures must have a respirator of the correct type ready to wear at all times.

Exits and gangways from areas where ammonia is used or stored must be kept clear and free from obstructions to permit rapid evacuation if there is a serious escape of ammonia. Locations from which evacuation can only be carried out with difficulty must be designated 'gas mask areas'. All persons entering such areas must be thoroughly trained in the use of respirators and carry one at the ready.

When purging ammonia or draining oil from the plant, it is essential to use a purge apparatus as a precaution against ammonia escaping into the plant room.

Hydrochlorofluorocarbon and Hydrofluorocarbon Refrigerants

Refrigeration systems contain liquid and vapour under pressure; personnel should be aware of this fact at all times. Suitable precautions must be taken to guard against the pressure hazard when opening any part of the system.

Opening up part of the primary refrigeration circuit will necessitate the loss of a certain amount of refrigerant to atmosphere. It is essential to restrict the amount which escapes to a minimum by pumping over and isolating the charge in another part of the system.

Where lubricating oil may be present, when changing the oil filter element for example, caution must be exercised as the oil will contain a certain amount of refrigerant which will be released when subjected to atmospheric conditions.

Refrigerant and lubricating oil, especially liquid refrigerant at low temperature, can cause freezing injuries similar to a burn if allowed to come into contact with the eyes or skin. Suitable protective clothing, gloves, goggles etc. must be worn when opening pipes or vessels which may contain liquid.

Although not considered toxic, being heavier than air, hydrofluorocarbon refrigerant vapour can endanger life by displacing air from cellars, ships engine rooms, etc. If refrigerant is released accidentally, fan assisted ventilation must be used to remove the vapour. Exposure levels in the workplace should be kept to a practicable minimum and certainly within the recognised threshold limit value of 1,000 parts per million (ppm) based on an 8 hour day, 40 hour week.

While hydrofluorocarbon refrigerants are not flammable, naked flames, for example, smoking, must be prohibited in the presence of vapour as temperatures above 300 °C will cause it to decompose and form phosgene, hydrogen fluoride, hydrogen chloride and other toxic compounds. If ingested, these compounds can have very dangerous physiological effects.

Refrigerant which is not required for immediate use must be stored in approved containers, and the quantity held in the plant room limited. Cylinders and drums of refrigerant must be treated with care.

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1. About this Publication

These instructions have been prepared according to the following standards:

BS 4884 : Technical Manuals:

Part 1 : 1992 Specification for Presentation of Essential Information.
Part 2 : 1993 Guide to Content.
Part 3 : 1993 Guide to Presentation.

BS 4899 : User's Requirements for Technical Manuals:

Part 1 : 1991 Content.
Part 2 : 1992 Presentation.

BS 4899 is based on the principles of BS 4884.

BS 5378 : Part 2 : 1982 Safety Signs.

1.1. Safety Warnings and Symbols

The system of safety warnings and symbols is based on BS 5378 : Part 2 : 1982 Safety Signs and BS 4884 : Technical Manuals : Part 1 : 1992 Specification for Presentation of Essential Information.

⚠ WARNING

This denotes an immediate hazard with a high likelihood of personal injury or death if instructions, including recommended precautions, are not followed. There is also a potential risk of damage to the product, process or its surroundings.

⚠ CAUTION

This draws attention to instructions which must be complied with to avoid damage to the product, process or its surroundings.

NOTE: draws attention to important additional information.

1.2. Units of Measurement

Quantities are expressed in SI units or SI derived units.

1.3. Terminology

Terminology, abbreviations and acronyms are those currently in use throughout the refrigeration and air conditioning industry.

1.4. Ordering Extra Copies

Obtain extra copies of these instructions from the address below:

J & E Hall International
Questor House,
191 Hawley Road,
Dartford,
Kent DA1 1PU
England

Telephone: +44 (0) 1322-394420
Fax: +44 (0) 1322-425161
Email: helpline@jehall.co.uk
Website: www.jehall.co.uk

2. Misuses that Invalidate Guarantee

Please note that the installer is responsible for the correct installation and commissioning of equipment and, on completion, the owner and/or user is responsible for its safe operation and maintenance.

Failure to comply with the following provisions will invalidate the guarantee as set out in J & E Hall International standard conditions of sale.

2.1. Application

The following is specifically prohibited:

(a) Operation outside the limits detailed in Appendix 1 Compressor Data.

(b) Use of any anti-freeze, trace chemical or other additive in the primary refrigerant system.

(c) Use of lubricating oils other than those specified by J & E Hall International; refer to publication 2-59 Lubricating Oils.

2.2. System Provisions

Refer to Appendix 2 Oil Support System Schematic Flow Diagrams. Items specifically required and which are considered mandatory are as follows:

(a) On all systems other than those using R717 (ammonia), fit an adequately sized refrigerant filter/drier, preferably of the type using renewable cores. Fit a sight-glass/moisture indicator.

(b) Fit an adequately sized oil filter for filtration to 10 micron (10μ) or better: $\beta 25 \geq 75$, $\beta 10 \geq 3$, $\beta 5 > 1$.

(c) Fit an adequately sized suction strainer having a mesh aperture of 250μ or better.

(d) If the system is fitted with an economiser, fit an adequately sized strainer in the economiser suction line. The strainer must have a mesh aperture of 250μ or better.

(e) To prevent excessive reverse rotation of the compressor at shutdown it is necessary to fit a non-return valve adjacent to the compressor in the suction and/or discharge lines:

- Single compressor application - either a suction or discharge non-return valve must be fitted. A non-return valve in the suction line must be located before the suction strainer.
- Multiple compressor application - all compressors must be fitted with a discharge non-return valve.

NOTE: discharge non-return valves must be sized according to the operating conditions.

(f) Adequate precautions must be taken to prevent oil or liquid refrigerant accumulating in the compressor when it is stopped; refer to 6.2. Oil Drain.

(g) The compressor will need cooling; refer to the HSO 2000 Series Compressor Application Manual and publication 2-122 Compressor Cooling, available from J & E Hall International.

If liquid injection cooling or thermosyphon oil cooling is used, a preferential supply of liquid refrigerant must be provided for cooling purposes. The priority supply must be arranged so that the cooling requirement is satisfied before liquid can flow to the evaporator(s); refer to publication 2-122 Compressor Cooling.

(h) Fit, and maintain in an operational condition, the cut-outs and other safety devices described in ,Appendix 1 Compressor Data illustrated in Appendix 2 Oil Support System Schematic Flow Diagrams.

Under no circumstances should the compressor be operated with cut-outs or other safety devices short-circuited or rendered inoperative by mechanical or electrical means.

(i) The plant controller is required to supply load/unload pulses to the capacity control solenoid valves; refer to 4. Capacity Control .

The control system must be interlocked to prevent the compressor starting unless the slide valves are at minimum load; refer to 4.1.1. Minimum Load Interlock.

For capacity control modulation, flow control valves must be fitted in the load and unload oil lines to and from the capacity control cylinder; refer to Fig 3 and Fig 4.

2.3. Prolonged Storage

If, for any reason, the compressor cannot be installed immediately and must be placed in prolonged storage, refer to 8. Prolonged Storage.

2.4. Commissioning Provisions

General commissioning procedures are described in 10. Commissioning and Operation.

The following provisions are considered mandatory:

(a) The system into which the compressor is installed must be dehydrated by evacuation to a pressure of no more than 2.0 mm Hg before charging and commissioning take place. Under no circumstances must the HallScrew compressor be used to evacuate or pump out the system.

The evacuation procedure is described in publication Part E : Evacuation and Dehydration, available from J & E Hall International.

NOTE: it is important to remember that evacuating the system does not remove moisture dissolved in synthetic ester lubricant; refer to (c).

(b) When a mineral oil is specified for compressor lubrication, maintain the acid number of the oil <0.05 by checking on a regular basis using a proprietary acid test kit.

(c) With HFC refrigerants, for example, R134a or R404a, it is necessary to use polyolester synthetic lubricants. Maintain the acid number of the compressor lubricating oil <0.15 by checking the oil on a regular basis using a proprietary acid test kit available from the oil supplier.

When using polyolester synthetic oils, care must be taken to ensure that contact between air and the lubricant is minimised. Spare oil must be adequately protected against contamination; refer to 10.8. Adding Oil to the System.

NOTE: compressor failure due to internal corrosion, copper plating, sludged oil or etching of internal components due to high acidity will be taken as evidence that the above provisions have not been complied with.

(d) Connect the compressor drive motor such that the compressor rotates anticlockwise when looking on the compressor shaft end (driven end); refer to 10.4. Checking Compressor Rotation.

3. General Description

The J & E Hall International HSO 2000 series of open drive compressors form part of the HallScrew family of positive displacement, oil injected, single screw compressors.

These compressors have been specially developed for refrigeration, air conditioning and heat pump applications, and can be applied to single stage and multi-stage systems using all normal refrigerants as well as many other process gases.

3.1. Main Features

- For use with R717 (ammonia), R22, R404a, R507A, R134a, R407c, R410a and R23.
- Designed and tested to international standards.
- Robust construction.
- Improved machine clearance control for maximum efficiency.
- Oil injected for maximum reliability.
- Balanced loading on main bearings for maximum bearing life.
- Enhanced slide valve geometry for capacity modulation with minimum loss of efficiency. Infinite adjustment between maximum (100 %) and minimum load (nominal 10 %).
- Economiser facility provided to improve operating efficiency, especially at high compression ratios.

  For further information refer to publication 2-129 Economiser Facility For HallScrew Compressors.
- Anti-clockwise rotation looking on the motor (driven) end. Intermediate gearbox required for gas engine drive.

3.2. Construction

The motion work, i.e. that part of the machine which performs the compression function, consists of three rotating parts; there are no eccentric or reciprocating motions. These fundamental components comprise the cylindrical main rotor in which are formed six-start, helically grooved screw threads with a spherical (hourglass) root form. The main rotor meshes with two identical toothed wheels each having eleven teeth. These wheels (or 'star rotors' as they are called owing to their shape), are made from a special synthetic material. They are located in a single plane diametrically opposite each other on either side of the main rotor with their axes at right-angles to the main rotor axis. As the main rotor turns, it imparts a freely rotating motion to the star rotors.

The star rotors are supported by metal backings which are cast in one-piece with the star rotor shafts. Although they are located in place on their backings, the stars are allowed to 'float' a small amount in a rotational sense. This floating action, combined with the low inertia and negligible power transmission between the main rotor and star rotors, effectively absorbs any minute vibrations of the star/main rotor combination. The star rotor shafts are supported at each end by taper roller bearings.

The main rotor is a dynamically balanced component, manufactured from cast-iron, keyed to the steel mainshaft which runs in rolling element main bearings. Where the shaft emerges from the casing, leakage of oil or refrigerant is effectively prevented by a specially designed mechanical seal.

The main rotor and star rotors are housed inside a one-piece, cast-iron main casing. The inside of the casing has a somewhat complex shape, but essentially consists of a cylindrical annulus which encloses the main rotor leaving a small clearance. Part of the annulus is cutaway at the suction end to allow the star teeth to mesh with the main rotor flutes. The discharge ports (one for each star), are positioned at the other end of the annulus. These ports convey the compressed gas into the discharge manifold, formed by a web cast between the annulus and the walls of the casing; this web separates the casing into two pressure zones. Except for the discharge manifold, suction pressure prevails elsewhere in the main casing.

Side covers are provided to allow easy access to the star rotors, star rotor shafts and bearings, without disturbing working tolerances. The discharge end cover can also be removed to inspect the capacity control mechanism. The compressor is provided with the choice of either top or bottom discharge; the unused connection is sealed off with a blank cover.

It is necessary to fit a suction strainer immediately before the compressor suction inlet. The strainer is designed to trap any dirt circulating with the refrigerant which might otherwise enter and damage the compressor.

To prevent reverse rotation of the compressor at shutdown it is necessary to fit a non-return valve adjacent to the compressor in the suction and/or discharge lines; refer to 6.4.2.

3.3. The Compression Process

In the construction of the HallScrew the helical flutes in the main rotor can be likened to the cylinders of a reciprocating compressor, the star rotor teeth taking the place of conventional pistons. Instead of using suction and discharge valves, gas flow in and out of the flutes (the cylinders) is controlled by fixed ports.

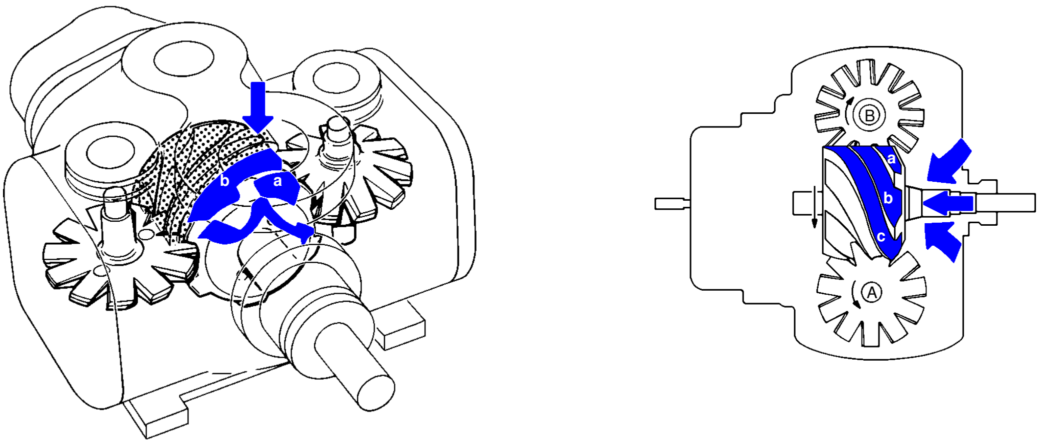
Gas enters the compressor through the suction connection and fills the available flutes. Rotation of the main rotor traps the gas in chambers formed by the flute walls, the cylindrical annular ring housing the main rotor, and the star teeth. The small clearances around the star teeth are sealed with oil which is injected into the compressor during operation. As the main rotor turns, the star teeth act as stationary pistons in the moving flutes (the cylinders), and the gas is compressed until a discharge port is uncovered. Each flute is used twice per rotor revolution, i.e. once by one tooth on each star.

The compression process is illustrated and described in detail in Fig 1.

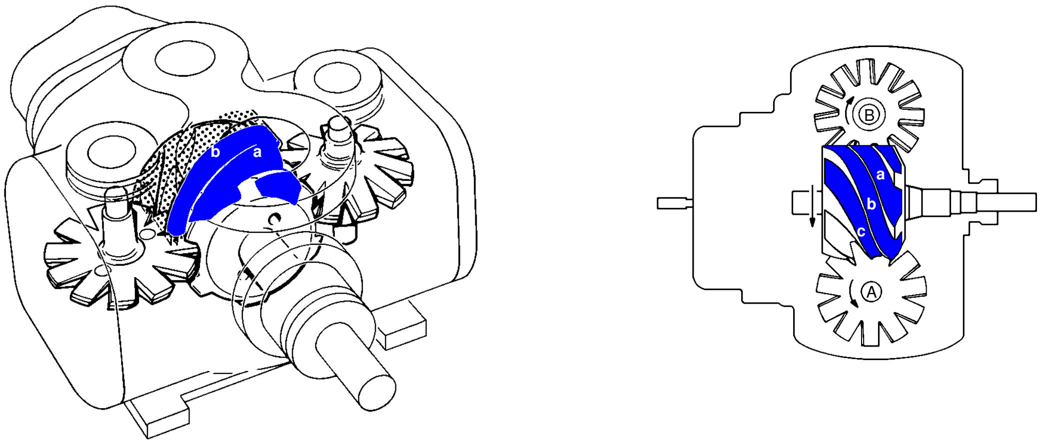
As the compression process is symmetrical, occurring at the same instant in each half of the compressor, this results in zero transverse gas pressure loads on the main rotor bearings. The axial loads are also minimal because the flutes terminate on the outer surface of the main rotor. The only bearing loads, apart from the weight of parts, are bending loads on the star rotor shaft bearings due to high pressure gas acting on one side of each tooth in mesh. There is also a small axial thrust load on the main rotor bearings resulting from the main shaft projecting through the casing, combined with the rotor vent pressure.

Capacity control is effected by slide valves, one for each half of the compressor. These valves are used to vent part of the gas trapped in the flutes back to suction, thus effectively shortening the compression length of the main rotor. Using this method, compressor capacity is infinitely variable between 100 % and 10 % of full load.

The movement of the slide valves is effected by oil pressure acting on a piston which is connected to the valves by a yoke. Pressurised oil is taken from the lubrication system and fed through solenoid valves which respond to signals from the plant control system. The solenoid valves direct oil to each end of the compressor capacity control cylinder via two connections positioned at the rear of the main casing, moving the capacity control piston in the appropriate direction to load or unload the compressor. Oil from the other end of the capacity control cylinder is vented to the low pressure (LP) side of the system via a connection in the suction line before the suction non-return valve.



1. SUCTION



2. SUCTION

Fig 1 Compression Process

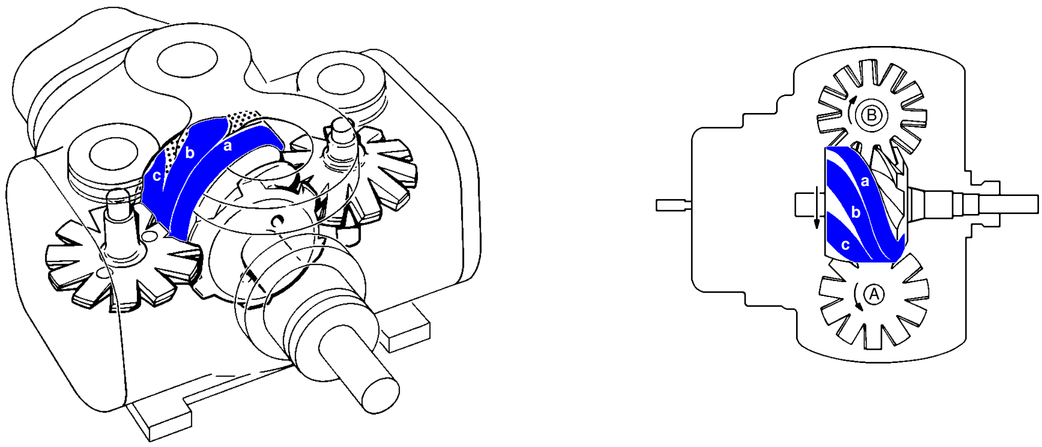
3.4. The Compression Process

As the HallScrew is a positive displacement compressor, there are three separate stages in the compression cycle: suction, compression and discharge. These are illustrated in Fig 1.

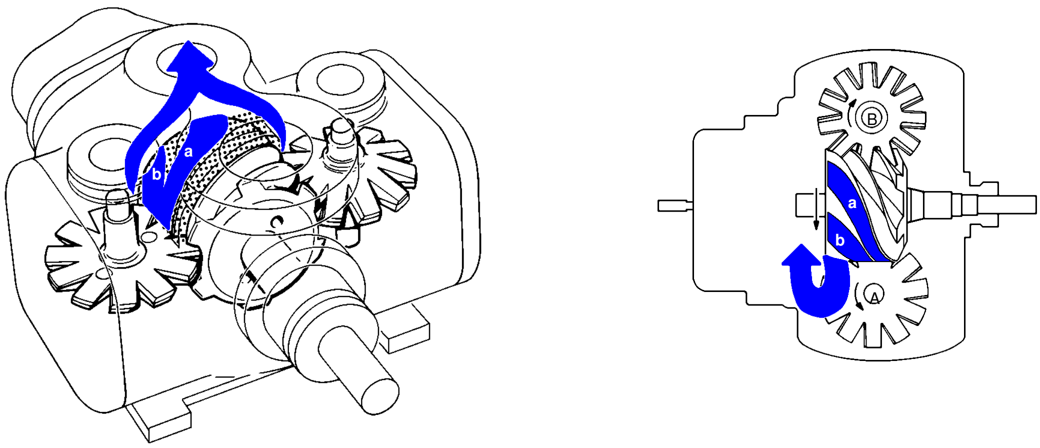
3.4.1. Suction

Main rotor flutes 'a', 'b' and 'c' are in communication at one end with the suction chamber via the bevelled rotor end face, and are sealed at the other end by the teeth of star rotor A. As the main rotor turns, the effective length of the flutes increases with a corresponding increase in the volume open to the suction chamber: Diagram 1 Fig 1 clearly shows this process. As flute 'a' assumes the position of flutes 'b' and 'c' its volume increases, inducing suction vapour to enter the flute.

Upon further rotation of the man rotor (diagram 2 Fig 1), the flutes which have been open to the suction chamber engage with the teeth of the other star rotor. This coincides with each flute being progressively sealed by the cylindrical annulus housing the main rotor (the outline of the annulus is shown as dotted lines). Once the flute volume is closed off from the suction chamber, the suction stage of the compression cycle is complete.



3. COMPRESSION



4. DISCHARGE

Fig 1 (continued) Compression Process

3.4.2. Compression

As the main rotor turns, the volume of gas trapped within the flute is reduced as the length of the flute shortens and compression occurs.

3.4.3. Discharge

As the star rotor tooth approaches the end of a flute, the pressure of the trapped vapour reaches a maximum value occurring when the leading edge of the flute begins to overlap the triangular shaped discharge port. Compression immediately ceases as the gas is delivered into the discharge manifold. The star rotor tooth continues to scavenge the flute until the flute volume is reduced to zero. This compression process is repeated for each flute/star tooth in turn.

While the compression process described above is occurring in the upper half of the compressor, there is an identical process taking place simultaneously in the lower half using star B, thus each main rotor flute is used twice per rotor revolution (one by one tooth in each star). The compression process may be likened to an assembly of six double-acting cylinders (the main rotor flutes) in which the star rotor teeth move as pistons (always in the same direction).

4. Capacity Control and Volume Ratio

Since the HallScrew compressor utilises fixed intake and discharge ports instead of valves, the overall compression ratio is determined by the configuration of these ports. The degree of compression is governed by the ratio between the flute volume when it is sealed off by the star tooth at the beginning of the compression process, to that immediately before the delivery port is uncovered. This is known as the built-in volume ratio (V_R) and is an important characteristic of all fixed-port compressors.

In order to achieve maximum efficiency, the pressure within the flute volume at the end of the compression process should equal the pressure in the discharge line at the instant the flute volume opens to discharge. Should these conditions not prevail, either overcompression or undercompression will occur, both of which result in internal losses. Although in no way detrimental to the compressor, inefficient compression will increase power consumption.

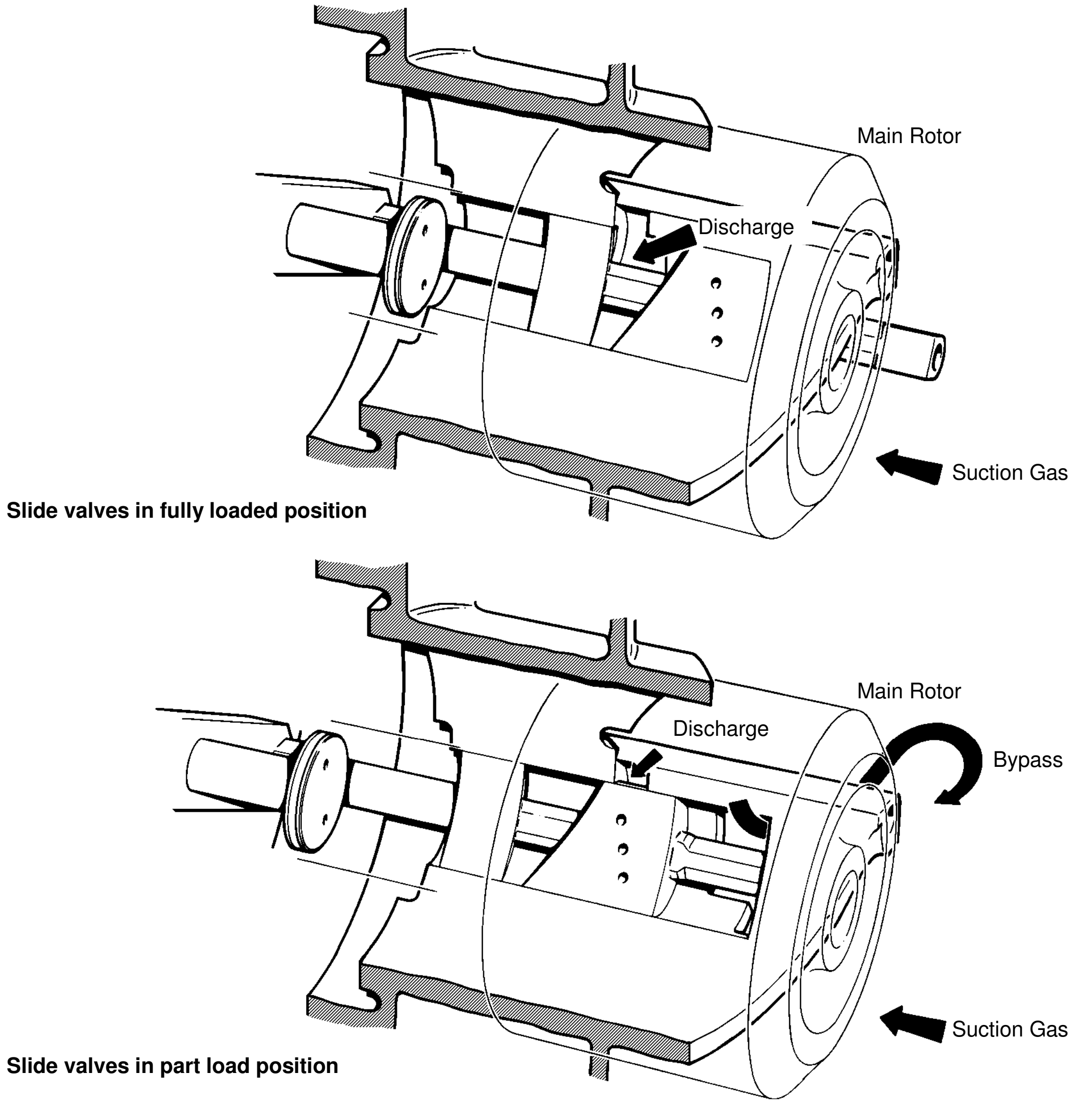


Fig 2 Capacity Control Slide Valve in Operation

The best part load characteristics are achieved if the design full load V_R is maintained as the compressor's capacity is reduced. The HallScrew 2000 series compressor is fitted with a pair of sliding valves, one for each half of the symmetrical compression process. These valves reduce pumping capacity by delaying the sealing of the flute volume together with the opening of the discharge port, altering the effective length of the main rotor flutes. The valves not only permit stepless capacity control down to approximately 10 % of full load (actual minimum value varies with operating conditions), but also maintain the best possible V_R over a wide capacity control range.

Each slide valve is housed in a semicircular slot in the wall of the annular ring which encloses the main rotor. As the slide valve travels axially from the full load position it uncovers a port which vents part of the gas trapped in the main rotor flute back to suction before compression can begin. When the flute has passed beyond the port, compression commences with a reduced volume of gas. However, a simple bypass arrangement without any further refinement would produce an undesirable fall in the effective volume ratio which in turn causes undercompression and inefficient part load operation. To overcome this problem, the slide valve is shaped so that it reduces the discharge port area at the same time as the bypass slot is created.

Fig 2 shows one of the capacity control slide valves in two positions: fully loaded and at part load, the arrows on the diagram indicating the flow of gas. Each half of the compressor is provided with its own slide valve system, these are operated simultaneously to maintain balanced gas loads and low bearing loads within the compressor. The position of the slot at the suction end of the slide and the position of the moving delivery port can both be chosen to give the desired full load V_R, the appropriate ratio being selected according to the operating conditions. The following volume ratio slides are available for each compressor size: 1.85, 2.2, 2.6, 3.5 and 4.9.

4.1. Slide Valve Actuation

The capacity control slides valves are joined together by a yoke which is connected to a hydraulic piston, housed inside a cylinder and mounted internally at the discharge end of the compressor.

The motive force required to actuate the piston is derived from a supply of pressurised oil taken from the lubrication system. The flow of oil to the cylinder is controlled either by a specially adapted 4-way solenoid valve or by two pairs of solenoid valves connected in parallel. As the requirement for duty changes, the plant control system energises or de-energises the solenoid valves, supplying oil pressure to drive the piston and slide valves in the load or unload direction. The oil on the other side of the piston is vented to the evaporator side of the suction non-return valve via a drain line.

The capacity control piston/slide valves speed of travel, and hence how quickly the compressor loads and unloads, is determined by flow control valves fitted in the load and unload oil lines to the capacity control cylinder.

4.1.1. Minimum Load Interlock

Starting at minimum load minimises motor starting current and starting torque. This in turn minimises stresses on the motor and mechanical parts, and also reduces the load on the power supply network.

The control system must be interlocked to prevent the compressor starting unless the linear variable displacement transducer (LVDT) provides an 'at minimum load' permit start signal.

If the slide valves are not already at minimum load, the pressure generated by the system oil pump is used to return them to the minimum load position.

4.2. Capacity Control Solenoid Valve Arrangements

As discussed in 7. Oil Circulation, if the system suction/discharge pressure differential is sufficient to generate oil pressure for injection and lubrication, an oil circulation pump can be dispensed with altogether. However, as there is no other oil pressure source, special precautions must be taken to automatically return the capacity control piston to the minimum load position when the compressor stops to provide a 'compressor on minimum load' interlock permit start signal for the next start. Therefore, instead of a 4-way solenoid valve, it is necessary to use two pairs of solenoid valves connected in parallel as illustrated in Fig 3. In this arrangement the solenoid valves in the unload path are reverse acting, i.e. energise to close. Hence when the compressor stops for whatever reason, and especially in the event of power failure, these valves will always de-energise (open) and unload the compressor.

The arrangement using separate pairs of solenoid valves must be used if the compressor is located in a Zone 1 or Zone 2 hazardous area where explosion-proof coils are a mandatory requirement. These coils cannot be fitted to the 4-way valve. The various capacity control solenoid valve options are summarised in Table 1.

APPLICATION	CAPACITY CONTROL SOLENOID VALVE ARRANGEMENT
No oil pump	Use separate pairs of solenoid valves
Oil pump runs at start-up only	A 4-way valve *or* separate pairs of solenoid valves can be used
Continuously running or demand oil pump	
All oil pump applications - compressor located in a Zone 1 or Zone 2 hazardous area	Use separate pairs of solenoid valves fitted with Valvex explosion-proof coils

Table 1 Capacity Control Solenoid Valve Options

4.3. Capacity Control Arrangement Using Separate Pairs of Solenoid Valves

This arrangement, shown in Fig 3, provides continuously variable capacity control between minimum and maximum load. There are two pairs of solenoid valves connected in parallel:

- Solenoid valves X and Y are normally open (NO), energise to close.
- Solenoid valves W and Z are normally closed (NC), energise to open.

4.3.1. Compressor Loading

With all the solenoid valves energised, valves W and Z are open, X and Y are closed. Pressurised oil flows through valve W into the load side of the capacity control cylinder, forcing the piston and slide valves in the load direction and increasing compressor pumping capacity. Oil on the unload side of the piston is forced through valve Z and drains to suction.

4.3.2. Compressor Unloading

With all the solenoid valves de-energised, valves W and Z are closed, X and Y are open. Pressurised oil flows through valve X into the unload side of the capacity control cylinder, forcing the piston and slide valves in the unload direction and decreasing compressor pumping capacity. Oil on the load side of the piston is forced through valve Y and drains to suction.

4.3.3. Hold Slide Valve Position

When solenoid valves X and Y are energised, valves W and Z de-energised, all the valves are closed, hydraulically locking the capacity control piston and slide valves at the desired load position.

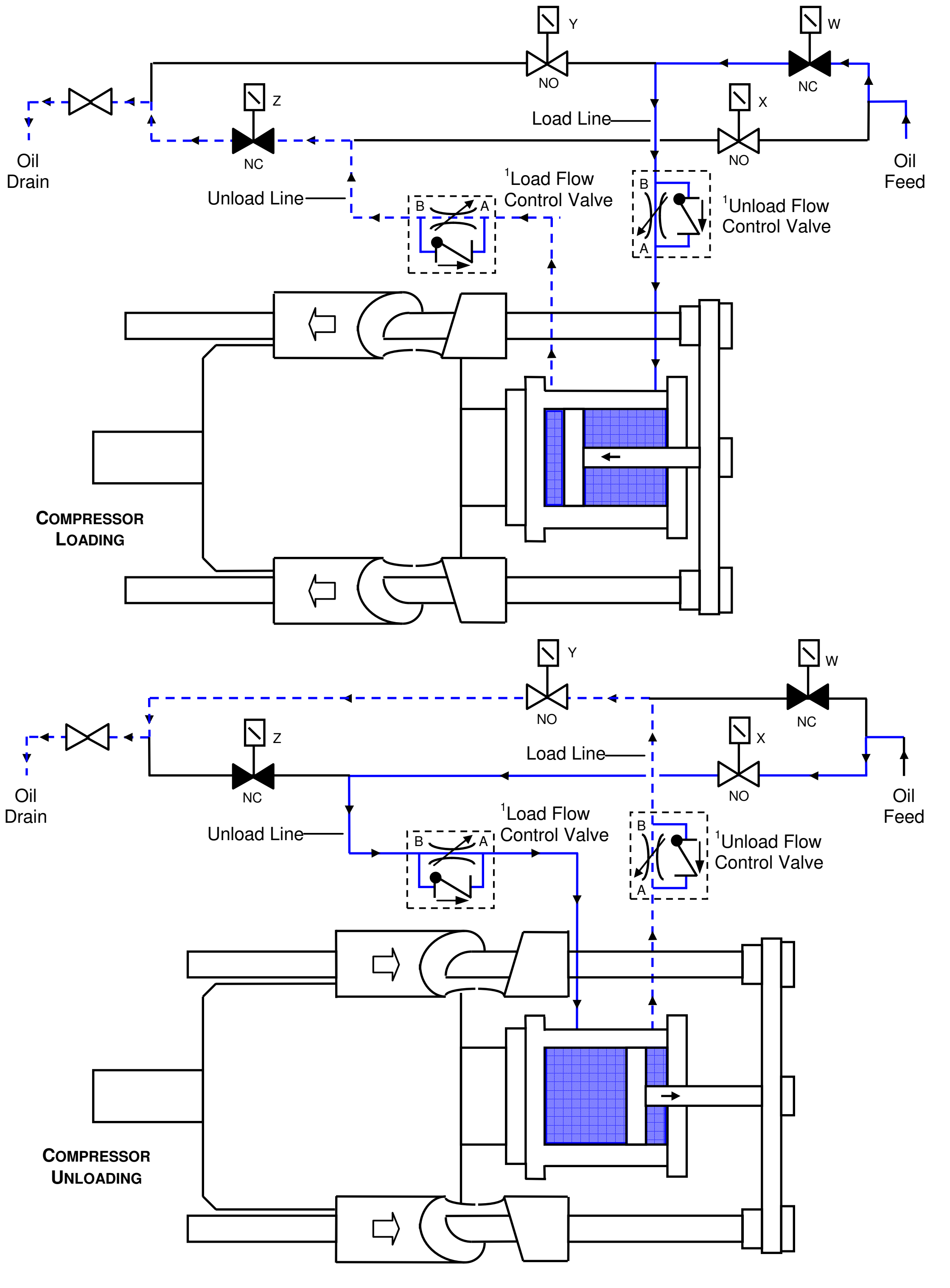
4.3.4. Flow Control Valves

The capacity control piston and slide valves speed of travel, and hence how quickly the compressor loads and unloads, is determined by flow control valves fitted in the load and unload oil lines to the capacity control cylinder. The time taken for the slide valves to travel from minimum to maximum load, and from maximum to minimum load, can be adjusted independently.

It is important to note that it is the flow control valve in the oil line connected to the *unload* side of the piston which controls the speed of *loading* while the valve connected to the *load* side of the piston controls the speed of *unloading*; this is illustrated in Fig 3.

- Closing the load flow control valve (turning the valve spindle clockwise) decreases the speed of loading, opening the load flow control valve (turning the spindle anticlockwise) increases the speed of loading.
- Closing the unload flow control valve (turning the valve spindle clockwise) decreases the speed of unloading, opening the unload flow control valve (turning the spindle anticlockwise) increases the speed of unloading.

If the plant controller permits the frequency and/or duration of the load and unload pulses to be adjusted, this feature can be used to supplement the flow control valves.



CAPACITY CONTROL ACTION	NORMALLY CLOSED (NC) SOLENOID VALVE W	NORMALLY OPEN (NO) SOLENOID VALVES X AND Y	NORMALLY CLOSED (NC) SOLENOID VALVE Z
Load compressor	Energise (open)	Energise (close)	Energise (open)
Unload compressor	De-energise (close)	De-energise (open)	De-energise (close)
Hold slide valve position	De-energise (close)	Energise (close)	De-energise (close)

[1]Flow control valves enclosed in boxes incorporate NRV as shown in Fig 11.

Fig 3 Capacity Control Arrangement Using Separate Pairs of Solenoid Valves

4.4. Capacity Control Arrangement Using a 4-Way Solenoid Valve

This arrangement, shown in Fig 4, provides continuously variable capacity control between minimum and maximum load. The solenoids on the 4-way valve are normally closed, energise to open.

4.4.1. Compressor Loading

Energising solenoid A (solenoid B de-energised) opens flow paths P → A and B → T. Pressurised oil flows through path P → A into the load side of the compressor capacity control cylinder, forcing the piston and slide valves in the load direction and increasing compressor pumping capacity. At the same time, oil on the unload side of the piston drains to suction through path B → T.

4.4.2. Compressor Unloading

Energising solenoid B (solenoid A de-energised) opens flow paths P → B and A → T. Pressurised oil flows through path P → B into the unload side of the compressor capacity control cylinder, forcing the piston and slide valves in the unload direction and decreasing compressor pumping capacity. At the same time, oil on the load side of the piston drains to suction through path A → T.

4.4.3. Hold Slide Valve Position

De-energising solenoids A and B returns the valve spool to the centre/off position, closing all the ports and hydraulically locking the capacity control piston and slide valves at the desired load position.

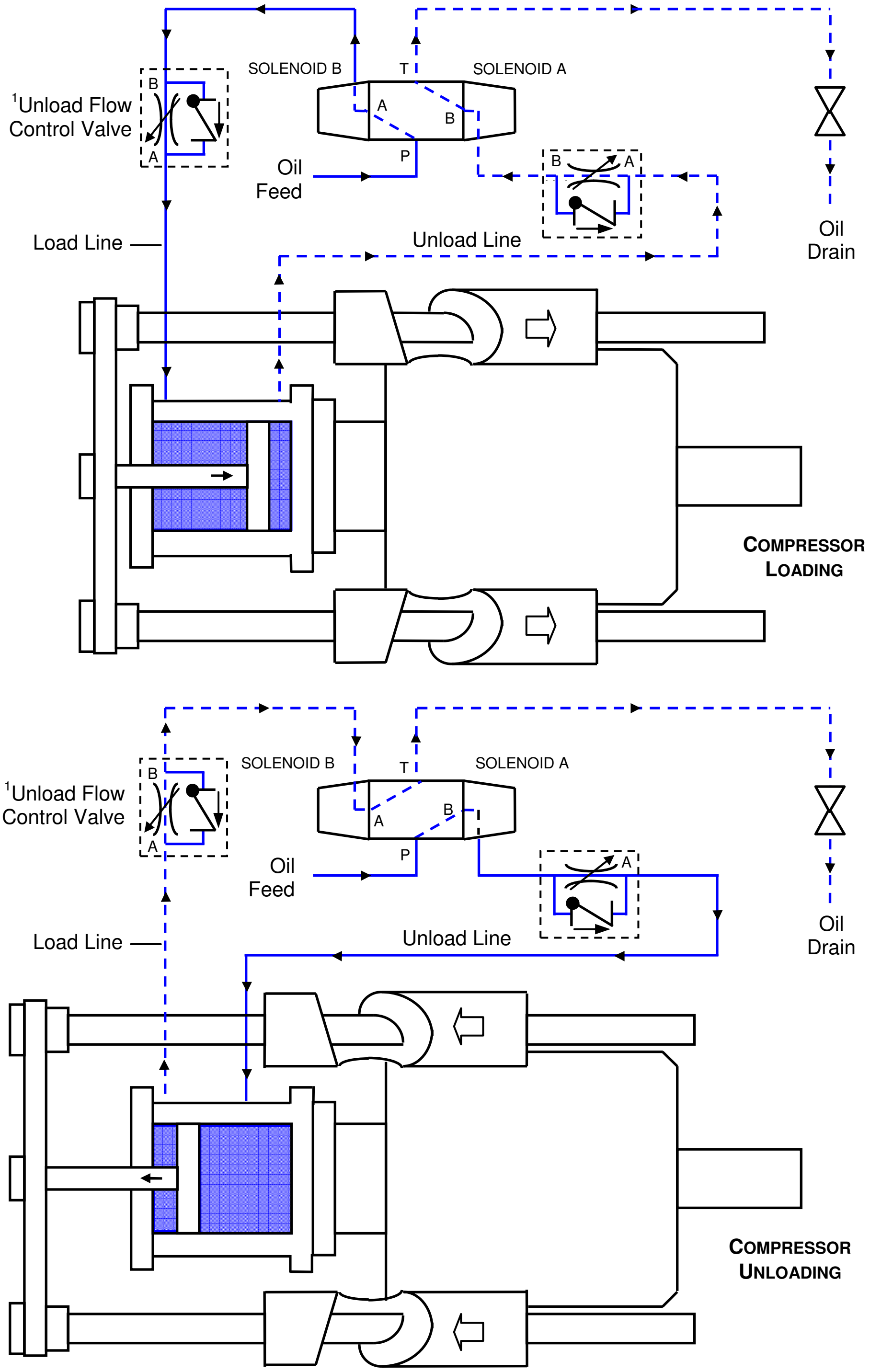
4.4.4. Flow Control Valves

The capacity control piston and slide valves speed of travel, and hence how quickly the compressor loads and unloads, is determined by flow control valves fitted in the load and unload oil lines to the capacity control cylinder. The time taken for the capacity control piston/slide valves to travel from minimum to maximum load, and from maximum to minimum load, can be adjusted independently.

It is important to note that it is the flow control valve in the oil line connected to the *unload* side of the piston which controls the speed of *loading* while the valve connected to the *load* side of the piston controls the speed of *unloading*; this is illustrated in Fig 4.

- Closing the load flow control valve (turning the valve spindle clockwise) decreases the speed of loading, opening the load flow control valve (turning the spindle anticlockwise) increases the speed of loading.
- Closing the unload flow control valve (turning the valve spindle clockwise) decreases the speed of unloading, opening the unload flow control valve (turning the spindle anticlockwise) increases the speed of unloading.

If the plant controller permits the frequency and/or duration of the load and unload pulses to be adjusted, this feature can be used to supplement the flow control valves.



CAPACITY CONTROL ACTION	[2]SOLENOID A	[2]SOLENOID B	OIL FLOW
Load compressor	Energise	De-energise	P → A, B → T
Unload compressor	De-energise	Energise	P → B, A → T
Hold slide valve position	De-energise	De-energise	No flow

[1]Flow control valves enclosed in boxes incorporate NRV as shown in Fig 11.
[2]The solenoids on the 4-way valve are normally closed, energise to open.

Fig 4 Capacity Control Arrangement Using a 4-Way Solenoid Valve

4.5. Capacity Control by Inverter Drive

Instead of using the slide valves, compressor capacity can be controlled using a frequency inverter (also known as Variable Speed Drive or Variable Frequency Drive). If an inverter is used, the load/unload solenoid valves need to be controlled to allow the compressor to start at minimum load but load to full load when the compressor is running. There are three methods of achieving this;

- Energise the load solenoid continuously irrespective of whether the compressor is running or not.
- Energise the load solenoid continuously when the compressor is running and the unload solenoid continuously when the compressor is stopped.
- Remove the plunger from the load solenoid valve (only) and do not fit the coils.

When using an inverter, it is of utmost importance that it is both sized and set up correctly.

4.5.1. Inverter Size

The inverter must be sized to deliver the maximum current taken by the compressor motor at the maximum power conditions – in most cases this is during pull down.

NOTE: the current capacity of an inverter drive is not reduced by running at less than synchronous speed.

During pull down, the current can be limited by either using the slide valves to run the compressor unloaded, or by throttling the suction. If it is required to use the slide valves during pull down, then normal manual slide valve control can be used; refer to 4.2. Capacity Control Solenoid Valve Arrangements.

4.5.2. Inverter Set-up

The inverter drive used must have the following facilities as a minimum;

- Load type: constant torque.
- Control method: PID (automatic) with facility for manual frequency control.

Particular attention has to paid to setting up the inverter with the correct minimum frequency, maximum frequency and acceleration time.

NOTE: minimum frequency and maximum frequency must be set according to the operating conditions; refer to J & E Hall International.

4.6. Linear Variable Displacement Transducer (LVDT)

The LVDT provides a continuous 4 to 20 mA slide valve position signal between minimum load (25 %) and maximum load (100 %). The LVDT operates on the principle of using a coil (inductance element) to produce an electrical output proportional to the displacement of a separate movable indicator rod. The indicator rod is spring-loaded and rests against the end of the capacity control piston. The complete assembly screws into a boss in the end of the compressor.

The LVDT electronics module is outside the pressure envelope of the compressor, eliminating any possibility of refrigerant leakage and allowing the module to be easily renewed in the event of failure.

⚠ CAUTION

The LVDT contains electronic components which are susceptible to the interference from mobile phones, portable radios or other devices which emit electromagnetic radiation. Such items must not be operated adjacent to the LVDT assembly.

Two designs of LVDT are fitted to HS 2000 series compressors:

- Until February 2008: HBLVDT, refer to 4.7.
- After February 2008: MSI LVDT (direct replacement), refer to 4.8.

4.7. HB Linear Variable Displacement Transducer (HBLVDT)

External wiring connections are illustrated in Fig 5 and Fig 6.

Two LEDs are provided: red for calibration and green for slide valve position indication.

An explosion-proof version of the HBLVDT is available; refer to Fig 6.

The HBLVDT 4 to 20 mA signal must be calibrated for minimum and maximum load using one of the following procedures.

4.7.1. 4 to 20 mA Calibration – Compressor Stopped

Before calibration can begin, arrange the compressor for manual loading/unloading (compressor stopped) using nitrogen gas as the pressure source.

The HBLVDT should be wired as shown in Fig 5 or Fig 6, check this point.

(a) Supply power to the HBLVDT at least 5 minutes before calibration begins.

(b) Unscrew and remove the cap covering the calibration button and LEDs.

(c) Using the manual load/unload arrangement, move the capacity control slides to the minimum load position. The slides must remain at minimum load for the duration of step (d).

(d) Press the calibration button once. The red LED will illuminate for 30 seconds, then ‘flash’ to indicate that the HBLVDT is ready for maximum load calibration.

(e) Using the manual load/unload arrangement, move the capacity control slides to the maximum load position. The slides must remain at maximum load for the duration of step (f).

(f) Press the calibration button once. The red LED will illuminate for 30 seconds then extinguish to indicate that calibration is complete.

(g) Refit the screw cap over the calibration button and LEDs.

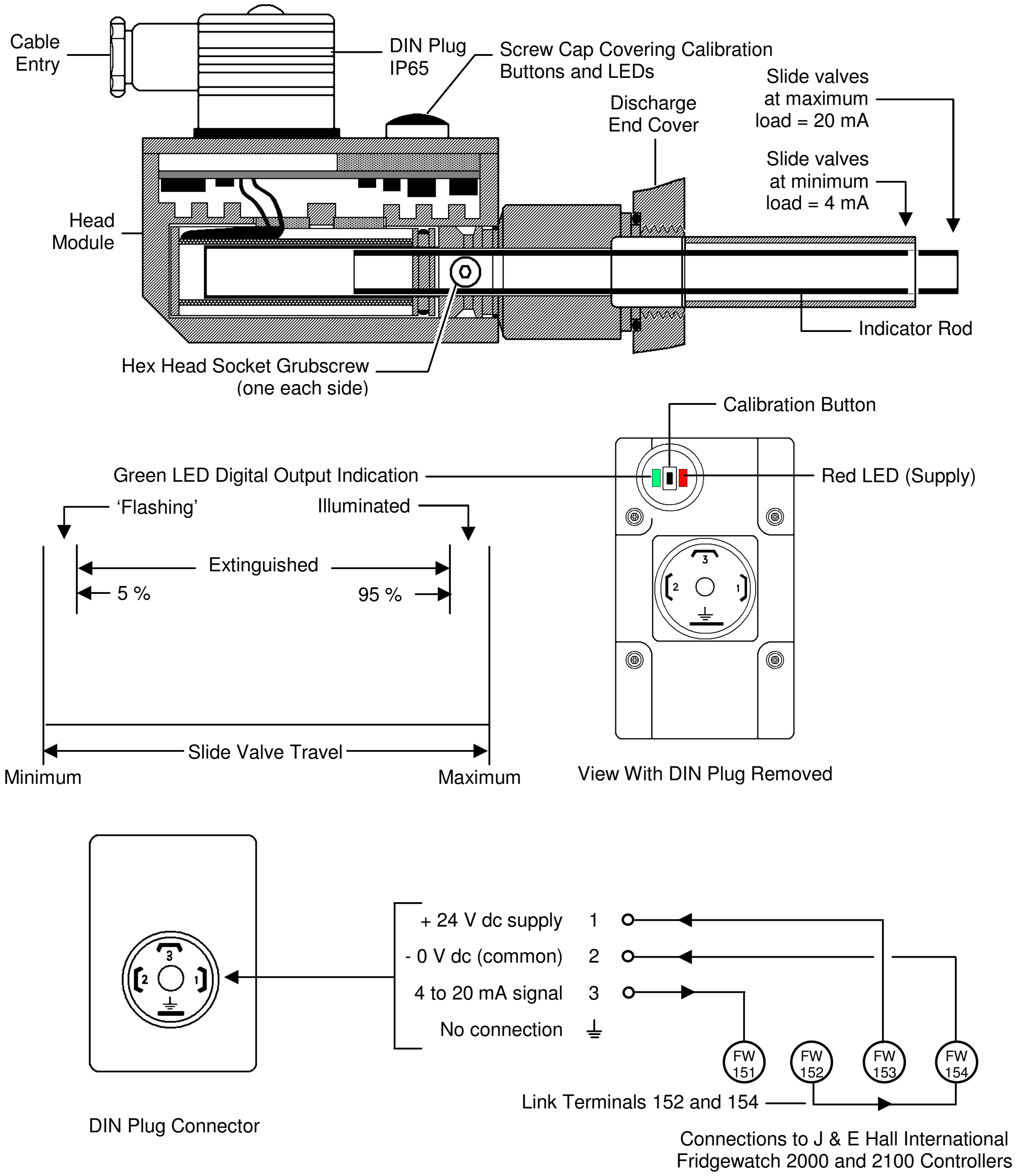


Fig 5 HBLVDT Arrangement and External Wiring Connections

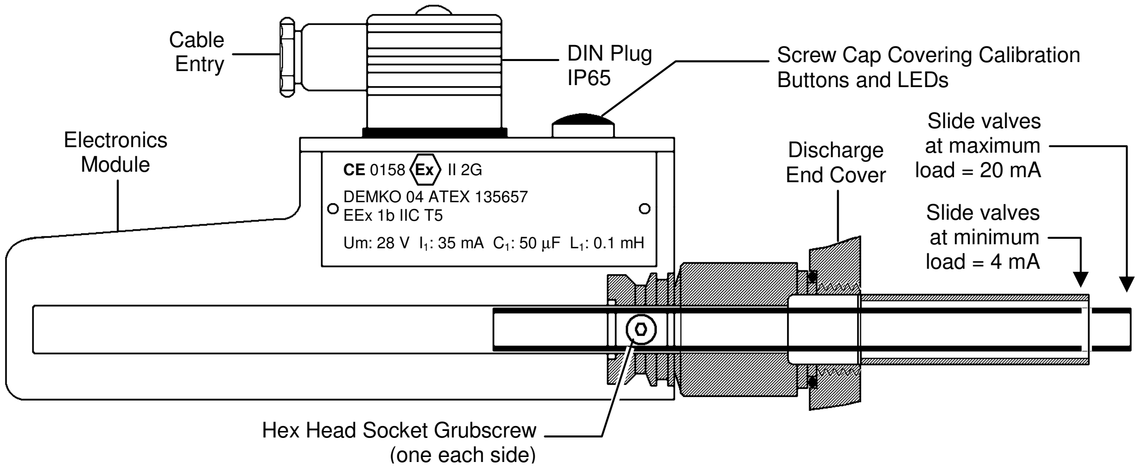
4.7.2. 4 to 20 mA Calibration – Compressor Running

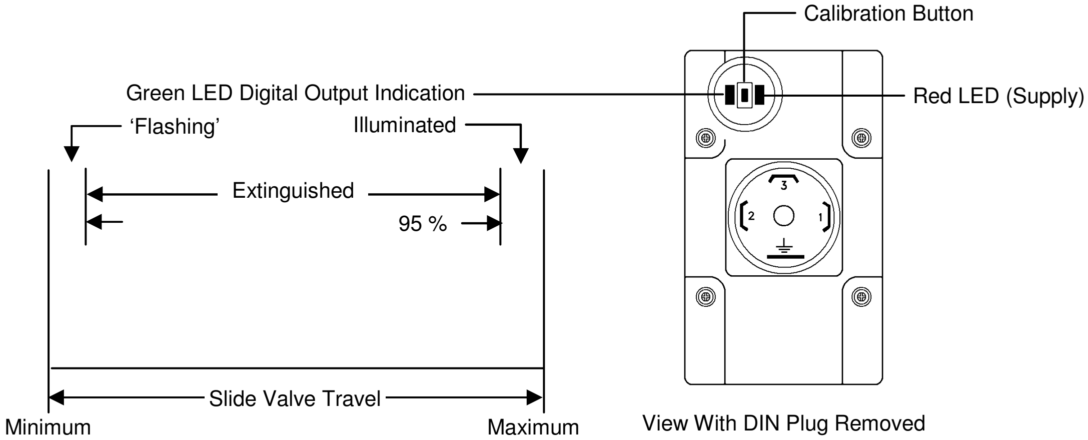
This procedure can be used instead of 4.7.1, however, sufficient heat load must be available to permit the compressor to run at maximum load long enough for the procedure to be completed.

The HBLVDT should be wired as shown in Fig 5 or Fig 6, check this point.

(a) Start the compressor if it was not already running. If the compressor will not start, refer to the notes at the end of this procedure.

(b) Supply power to the HBLVDT at least 5 minutes before calibration begins.





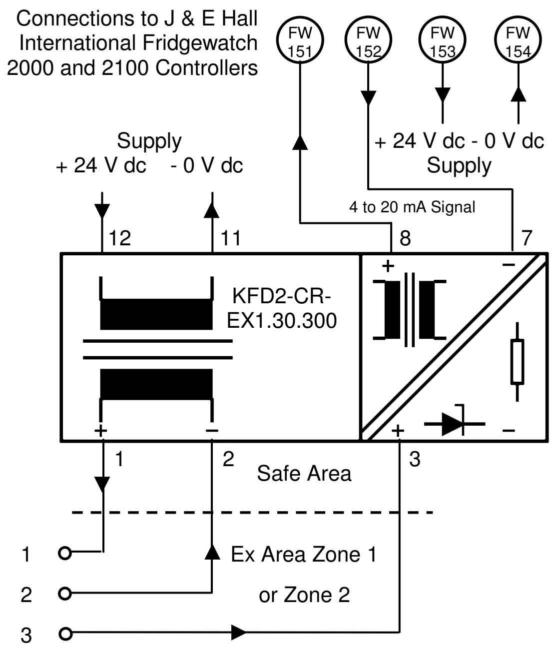
Specification

The power supply/amplifier must meet the following criteria:

Supply voltage = 12 to 28 V dc
Short-circuit current = 50 mA (minimum)
Transformer type = isolated
Approval = ATEX

When used in an Ex area the installation must be carried out according to EU norm EN 60079-14 general terms and IEC 79-11 intrinsic safety 'I'.

The equipment must be electrically connected via an approved or certified galvanically isolated interface/zener barrier placed outside the hazardous area. Pepperl + Fuchs Ex barrier type KFD2-CR-EX1.30.300 (illustrated) is recommended.



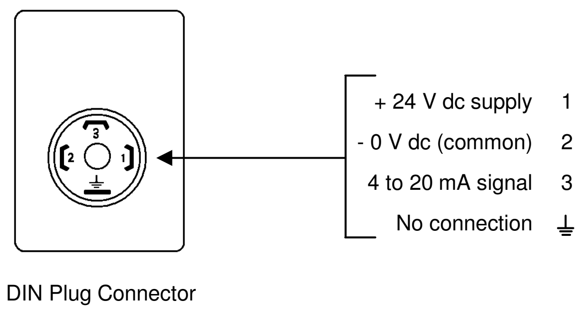


Fig 6 HBLVDT External Wiring Connections for Explosion-Proof Version

(c) Unscrew and remove the cap covering the calibration button and LEDs.

(d) Select 'hand capacity control'. Move the capacity control slides to the minimum load position. The slides must remain at minimum load for the duration of step (e).

(e) Press the calibration button once. The red LED will illuminate for 30 seconds, then 'flash' to indicate that the HBLVDT is ready for maximum load calibration.

(f) Check 'hand capacity control' is selected. Move the capacity control slides to the maximum load position. The slides must remain at maximum load for the duration of step (g).

(g) Press the calibration button once. The red LED will illuminate for 30 seconds then extinguish to indicate that calibration is complete.

(h) If the compressor was not already running and at operating temperature, wait until steady operating temperature is achieved before repeating the calibration procedure from (d) to (g).

(i) Refit the screw cap over the calibration button and LEDs.

To calibrate the HBLVDT using the procedure described in 4.7.2 it is necessary to run the compressor. If the compressor does not start the calibration may be so far out that the plant controller will flag an analogue input error on the HBLVDT channel, or the signal may be so far away from 4 mA that the controller does not consider that the compressor is at minimum load. The compressor is interlocked to prevent starting unless the slide valves are at minimum load, refer to 4.1.1, therefore, either of the above conditions will result in the controller refusing to allow the compressor to start.

To enable the compressor to start under these circumstances and to allow the compressor to continue running during the HBLVDT calibration procedure, the plant controller must provide a way to temporarily disable the 'minimum load interlock' and the 'HBLVDT analogue out-of-range error trip'.

⚠ CAUTION

It is essential for safe compressor operation that the minimum load interlock and the HBLVDT analogue out-of-range error trip are both re-enabled as soon as the calibration of the HBLVDT is completed.

4.7.3. Fitting a New HBLVDT Electronics Module

In the event of malfunction, the HBLVDT electronics module can be replaced without disturbing the compressor pressure envelope.

NOTE: the electronics inside the module can be damaged by static discharges so take all relevant precautions, including earthing yourself before touching the module. Also, it is important that the 24 V dc power supply to the HBLVDT is turned off before removing the old module or fitting the new one.

(a) Switch off the 24 V dc power supply to the HBLVDT. Disconnect the DIN plug.

(b) Loosen the 2 hex head socket grubscrews which secure the module to the stainless steel pressure containment body. Carefully withdraw the module.

(c) Fitting the new module is the reverse of the dismantling sequence. Tighten the 2 grubscrews evenly and alternately.

(d) Reconnect the DIN plug and switch on the 24 V dc power supply to the HBLVDT. Check the calibration as described in 4.7.1 or 4.7.2.

4.8. MSI Linear Variable Displacement Transducer (MSI LVDT)

From the February 2008, all HS 2000 compressors are supplied with the MSI LVDT which replaces the HBLVDT previously fitted.

- The MSI LVDT is a drop-in replacement for the HBLVDT. Adaptors, spacers etc., are not required; refer to Table 2.
- The MSI LVDT is only available without calibration, this must be done on the controller. However, a signal conditioning module is available, part number 2848-601, for applications where this is not possible. The module is suitable for DIN rail mounting; refer to Fig 8.
- The method of 4 to 20 mA signal calibration using the signal conditioning module is described in Appendix 6 Pepperl & Fuchs Signal Conditioning Module KFU8-USC-1.D Set-up.

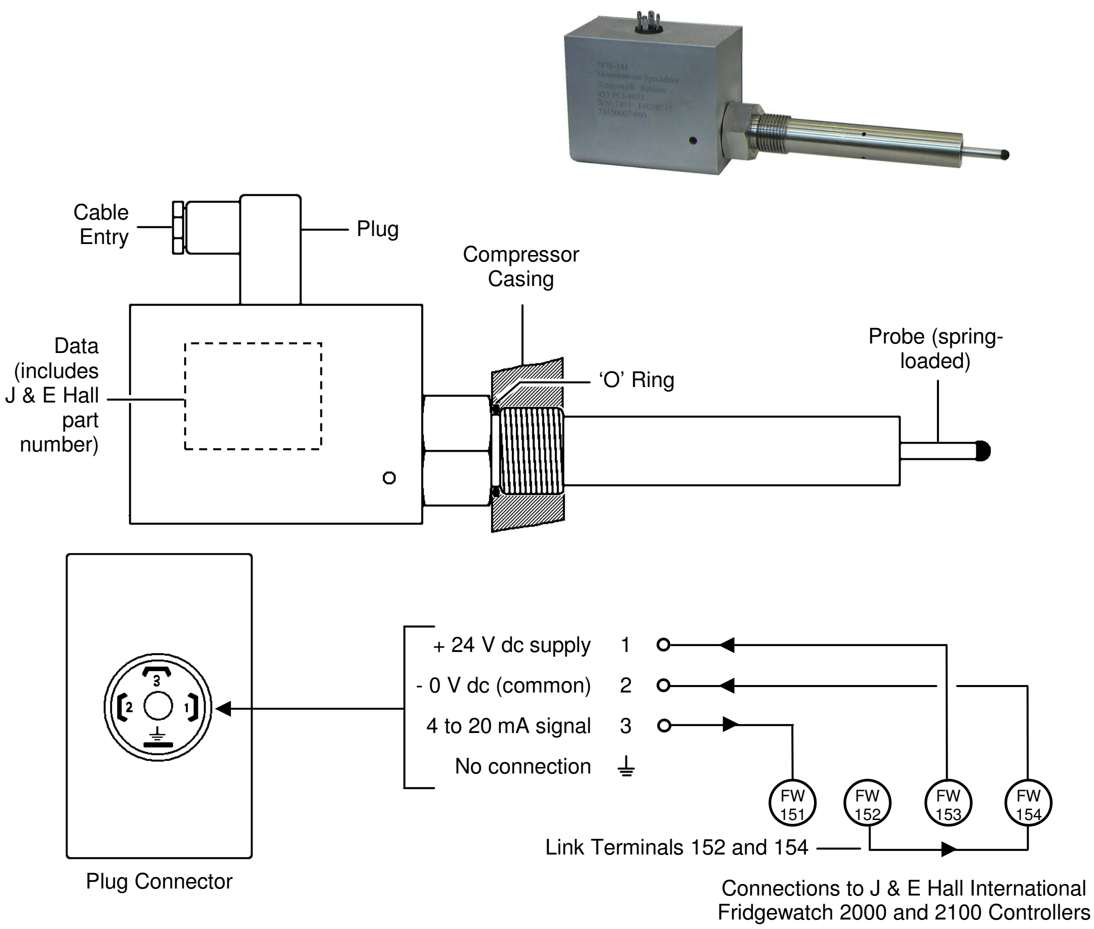
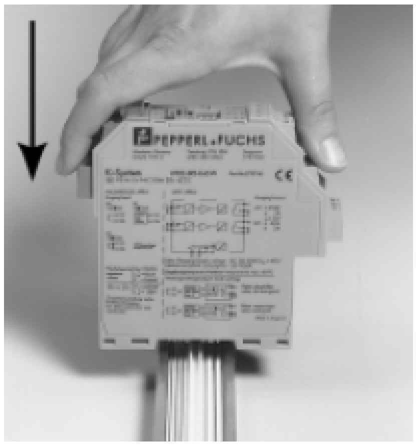
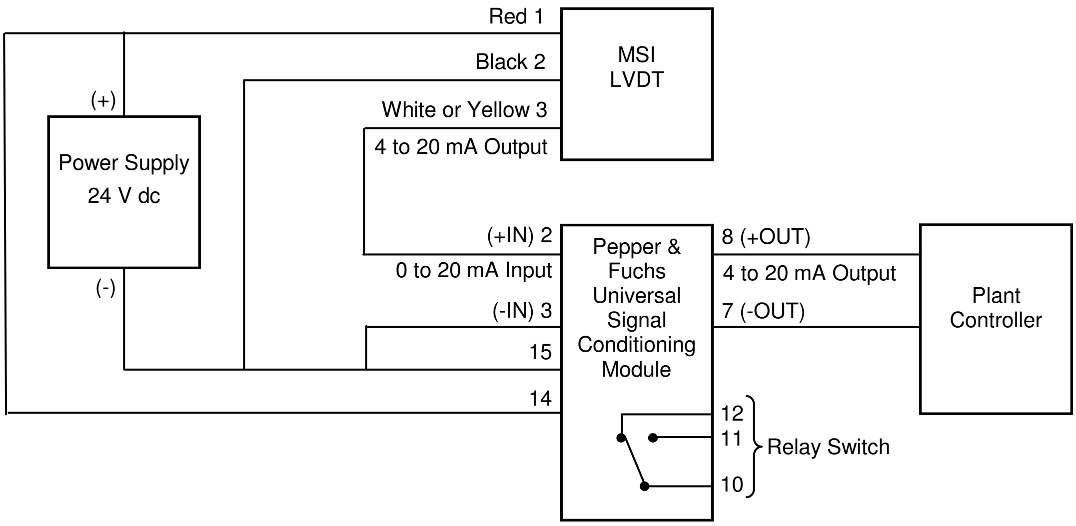


Fig 7 MSI LVDT Arrangement and Wiring Connections

Pepperl & Fuchs Module KFU8-USC-1.D
Part Number 2848-601



Suitable for DIN Rail Mounting



Wiring for MSI LVDT and Pepperl & Fuchs Universal Signal Conditioning Module

Fig 8 Signal Conditioning Module

[1]J & E Hall Part Number		HallScrew Compressor Series	
MSI LVDT	**HBLVDT**		
7876-143	7876-120	HS 2024	HS 2000
7876-144	7876-121	HS 2028	
7876-145	7876-122	HS 2031	
7876-146	7876-123	HS 2035	

[1]The J & E Hall part number appears on the body of the MSI LVDT.

Table 2 MSI LVDT/HBLVDT Part Number Cross-reference

5. Compressor Lubrication, Sealing and Cooling

In common with other types of oil injected screw compressor, HSO 2000 series compressors do not possess a built-in oil reservoir (sump), oil circulation pump or oil filtration equipment. Instead, oil is supplied by a separate external oil support system.

NOTE: it is essential to supply the compressor with an adequate supply of clean (filtered) oil at the correct temperature; refer to 6. Oil Support System.

The oil performs four basic functions:

5.1.1. Capacity Control Actuation

Oil pressure is used to actuate the compressor capacity control mechanism; refer to 4. Capacity Control .

5.1.2. Bearing Lubrication

The rolling element bearings used in the construction of the HallScrew compressor require a steady but relatively small supply of oil for satisfactory operation and long life. The oil injected for sealing and cooling also lubricates the star shaft bearings, however, the main bearings and gland seal assembly require a specific oil supply.

The rear main bearings are supplied with oil from a connection positioned at the lower rear of the main casing. The oil is conveyed through a pipe to the space behind the bearings, flows through the bearings and drains into the main casing.

5.1.3. Shaft Seal Lubrication, Sealing and Cooling

The main shaft gland seal is a balanced mechanical type comprising a rotating, spring-loaded sealing face element fixed to the shaft and a stationary sealing face element located in the cover plate attached to the shaft seal housing. Each sealing face has a highly polished optically flat surface separated by a thin oil film which provides an effective seal to minimise oil/refrigerant leakage.

The seal assembly is supplied with oil via a connection on the gland housing. The oil both lubricates the moving surfaces and carries away the heat generated at the gland seal faces. After flowing through the gland, the oil lubricates and cools the front main bearing before draining into the main casing.

5.1.4. Oil Injection for Sealing and Cooling

The fourth oil supply, which is the predominant oil usage, provides oil for injection to seal the compression process. Oil is injected through two connections; refer to Appendix 1 Compressor Data.

In the design of the compressor the star rotor teeth must form an effective seal with the flute profiles in the main rotor, while at the same time maintaining a satisfactory operating clearance. The main rotor flute/star tooth profile enables hydrodynamic and hydrostatic actions to combine to provide a wedge of oil at this point. Between the main rotor and the casing, and in several other positions where a pressure differential is separated by two surfaces moving relative to each other, the oil injected provides a sealing film enabling effective compression to take place. The oil also has a silencing effect.

The oil for sealing and cooling is supplied to the capacity control slide valves via oil tubes. The valves are free to move back and forth along the axis of the tubes, escape of oil being prevented by a specially designed bearing located on their inner circumference. Three drillings on the inner face of each slide inject oil into the main rotor flutes.

Positioning the oil injection ports in the capacity control slide valves ensures that, at all slide valve positions, oil enters the main rotor flutes after the flute volume has been sealed, i.e. oil injection always occurs during the compression process over the whole capacity control range, thus ensuring maximum pumping efficiency. Because oil is injected over a period in the compression process when the pressure of the gas trapped in the flutes is considerably lower than discharge pressure, this means that in the majority of instances the system pressure difference can be used to provide the required oil flow without the need for an oil pump running continuously while the plant is in operation; refer to 7. Oil Circulation.

Compressor cooling can be accomplished by the direct injection of liquid refrigerant into the compression process. When liquid injection is not used, the oil injected for sealing absorbs a large proportion of the heat of compression, thus reducing the maximum discharge temperature, and is cooled externally via an oil cooler; refer to 7.4. Compressor Cooling.

6. Oil Support System

HSO 2000 series compressors require an external oil separator and oil support system; refer to Appendix 2 Oil Support System Schematic Flow Diagrams.

NOTE: the system into which the compressor is to be installed must fully comply with the recommendations in 6.1. to 6.4. and 7. Oil Circulation. Failure to do so could result in deterioration of the compressor, both mechanically and functionally.

6.1. Oil Injection/Lubrication

Separate lines are required to provide oil for injection, lubrication and capacity control actuation. The connection sizes can be found in Appendix 1 Compressor Data.

If it is required to fit service valves in these lines, they should be full-flow ball valves to minimise pressure drop.

6.2. Oil Drain

Oil which collects inside the compressor casing must be allowed to drain back to the oil separator when the compressor stops. An oil drain facility, including a non-return valve, forms an integral part of HallScrew 2000 series compressors. Oil is automatically drained into the discharge line immediately inside the lower discharge flange.

If a discharge non-return valve is fitted between the compressor and oil separator or when the discharge line rises above the compressor, the internal drain ceases to function. In such applications, and for all low stage (booster) and other low pressure difference applications where a continuously running oil pump is used, provision must be made for an external drain line, fitted with an oil drain sensor to prevent the compressor starting unless the drain line is clear; refer to 6.2.1. Oil Drain Sensor.

To ensure the oil drain line functions correctly:

- The drain line must slope down all the way to the separator without traps or risers. If it is required to fit a service valve in this line, this should be a full-flow ball valve to minimise pressure drop.
- The drain line must incorporate a non return valve to allow oil to flow from the compressor to the separator during shut down, but prevent flow in the opposite direction when the compressor is running. The non-return valve is required to open with zero head.

6.2.1. Oil Drain Sensor

If the compressor capacity slide valves are not at the minimum load position before starting, the pressure generated by the oil pump is used to return them to minimum load. However, when it is necessary to fit a continuously running oil pump, for example a low stage (booster) application, there is a danger that the pump will partially fill the compressor with oil. For these applications it is necessary to fit an opto-electronic liquid sensor into an external drain line from the compressor (refer to Fig 14), electrically interlocked to prevent the compressor from starting until the drain line is clear of liquid: refrigerant and/or oil.

6.3. Oil Separation

All the oil injected into the compressor for lubrication, sealing and capacity control actuation, ultimately ends up in the discharge gas stream. During its passage through the compressor the oil is thoroughly mixed with the refrigerant, eventually ending up in the discharge gas stream as a fine mist of oil droplets. Before the oil can be recirculated it must be separated from the discharge gas, filtered, cooled (if compressor cooling is required and internal cooling by liquid injection is not used), and then returned to the compressor. An oil separator is therefore required in the discharge line. This vessel effectively removes the majority of the oil constituent from the oil/gas mixture, the oil draining into a reservoir which usually forms the lower portion of the separator vessel.

6.3.1. Oil Separator Design

The method of oil separation utilised by the oil separator is not important in itself in that velocity, impingement coalescent or other types or combination of types may be used. However it is important that the separator operates at sufficient efficiency over the actual operating range, with the compressor at all load conditions.

Deciding the required level of efficiency is important and is dependant not only on the compressor but also on the system design. No separator is 100 % efficient and some oil will always be carried over into the system. On a small direct expansion system this oil will be rapidly recirculated back to the compressor travelling with the refrigerant through the system and returning via the suction line. In this case the separator can be sized such that allowing for the extremes of operation, sufficient oil is maintained in the oil separator to ensure an adequate head of oil to match the specified oil flow rate from the separator into the compressor.

Additionally, as the separator efficiency changes with load and operating conditions, then the amount of oil carried into the system through the separator will also vary. Therefore the oil remaining in the separator will vary by an equal amount. Thus either sufficient oil capacity must be provided in the separator to allow for this change in oil quantity or a more consistent separator performance must be attained. As high quantities of oil in the evaporator are detrimental to system performance it is normal to design the separator with as high an efficiency as is economically achievable. Even in this case the separator must provide sufficient oil volume above the normal operating volume to cater for the variation in efficiency. In addition the separator must have sufficient oil volume to provide an adequate dwell time to allow oil and refrigerant to reach their equilibrium condition.

In systems such as those incorporating flooded evaporators where oil carried over from the separator is not so readily or quickly returned then greater care is required in oil separator design. The separator must be of sufficient efficiency that oil carried over into the system can be returned by the oil rectification system. For miscible oil/refrigerant combinations a sample of refrigerant is taken from the evaporator the refrigerant boiled off and the oil returned to the compressor. If this refrigerant is not boiled off in a useful fashion then this is a direct loss on the system performance. If conditions change rapidly then it can take considerable time for equilibrium to be achieved. Under these conditions oil will build up in the evaporator and be lost from the separator. Thus the separator must be of a high efficiency type perhaps including coalescent elements and at the same time must have sufficient oil volume above the minimum requirement to cope with these variations in operating conditions.

6.4. Oil Separator Provisions

In addition to the considerations discussed in 6.3.1, the oil separator should comply with the following recommendations:

6.4.1. Oil Return

As already mentioned in 6.2, the separator must be positioned at a suitable height such that the standing oil level (compressor stopped) is significantly below the bottom of the compressor. For applications using a continuously running oil pump a drain line must be installed between the compressor casing and the oil separator.

The oil separator must have a sufficient free volume to accommodate the oil drainage from the compressor or oil returned from another part of the system.

6.4.2. Suction/Discharge Non-return Valve

To prevent excessive reverse rotation of the compressor at shutdown it is necessary to fit a non-return valve adjacent to the compressor in the suction and/or discharge lines:

- Single compressor application - either a suction or discharge non-return valve must be fitted. A non-return valve in the suction line must be located before the suction strainer.
- Multiple compressor application - all compressors must be fitted with a discharge non-return valve.

  NOTE: discharge non-return valves must be sized according to the operating conditions.

6.4.3. Oil Heaters

The separator must be fitted with oil heaters of sufficient capacity to maintain an oil temperature 20 °C above the ambient temperature, thereby preventing refrigerant migration into the oil and the resultant loss of viscosity and potential foaming. The oil heaters must be electrically interlocked to energise when the compressor stops.

If the plant is sited in a cold environment then oil lines must be suitably lagged and if necessary heater tape applied in order to prevent oil foaming.

6.4.4. Oil Low Level

A level switch or sensor must be fitted to the oil separator or the main oil line at a point corresponding to a dangerously low oil level. The switch or sensor must be electrically interlocked to prevent the compressor starting unless there is sufficient oil in the reservoir, and stop the compressor should the oil level fall below the danger level.

6.4.5. Oil Balance Lines

In installations using multiple compressors/oil separator units on the same refrigeration circuit, oil returning from the system must be distributed such that an adequate oil level is maintained in each oil separator. If an oil balance system is adopted that relies on solenoid valves to prevent oil returning to the separator when the compressor is stopped, these solenoid valves must be selected and tested as suitable for use with refrigeration oils. Many such valves fail to close, with the possibility of oil flowing through the non running oil system/compressor and filling the compressor. This can occur even when a non return valve is fitted after the separator.

7. Oil Circulation

An oil circulation pump can be dispensed with for most operating conditions using HSO 2000 series compressors or if a pump is necessary it is only required to run at start-up.

For applications without an oil pump, oil circulation is maintained by the pressure difference generated between the high pressure side of the system and the pressure in the sealed main rotor flute at the point of oil injection. When the compressor stops, a special, fail-safe solenoid valve arrangement (refer to Fig 3) automatically returns the capacity control slide valves to minimum load.

For applications using an oil pump for starting only, the pump is used to provide adequate lubrication for the bearings and mainshaft gland seal, and an oil pressure source to return the compressor capacity control slide valves to the minimum load position prior to starting. After a short period the pump is stopped and oil injection maintained by the system pressure difference. Non-return valves are positioned in the oil lines to ensure that oil is only delivered to the lubrication and capacity control connections when the pump is running. When self-injection takes over, oil is fed to the lubrication, capacity control and oil injection connections.

Exceptions to the above occur when there is only a small system pressure difference. Typical examples are under low ambient conditions, low load operation and most low stage (booster) applications. If the difference between absolute discharge pressure, measured at the outlet from the oil separator, and twice the absolute suction pressure is less than 2 bar abs, pumped oil injection/lubrication is necessary using a full-flow oil pump running continuously while the compressor is operating. For minimum pumping capacities refer to Table 3.

HallScrew Compressor	Pumping Capacity m^3/hr	HallScrew Compressor	Pumping Capacity m^3/hr
HSO 2024	4 to 6	HSO 2031	7 to 10
HSO 2028	5.5 to 8	HSO 2035	10 to 15

Table 3 Pumping Capacities For Continuously Running Oil Pump

Oil support systems, similar to those fitted to J & E Hall International package units fitted with the HallScrew 2000 series compressor, are illustrated in Appendix 2 Oil Support System Schematic Flow Diagrams. All necessary valves, controls and instrumentation are shown in the diagrams.

7.1. Oil Differential Pressure Monitoring

As already discussed in 7. Oil Circulation, there are four basic oil support systems depending on whether an oil pump is fitted and its behaviour.

- No oil pump, system suction/discharge pressure differential is high enough to maintain oil follow.
- Start-up oil pump, runs to lubricate the gland and bearings before the compressor starts, then stops. When the compressor starts, system suction/discharge pressure differential is high enough to maintain oil flow.
- Continuously running oil pump, for low system pressure difference applications, starts and stops with the compressor.
- Demand oil pump, combines features of a start-up and a continuously running oil pump.

Each oil support system can be combined with two different oil feed types:

- Common oil supply feeds to the compressor oil injection port and to the gland and bearings.
- Separate oil supply feeds. The compressor oil injection port has it's own separate solenoid valve in the oil feed line which is not supplied from the oil pump (if fitted). The oil supply feed to the gland and bearings has it's own solenoid valve and is supplied from the oil pump (if fitted).

The oil differential pressure monitoring requirements for each oil support system are summarised in Table 4.

<table>
<tr><th colspan="5">STANDARD SOLENOID VALVE AND PRESSURE SENSING ARRANGEMENT</th></tr>
<tr><th rowspan="2">OIL DIFFERENTIAL PRESSURE (ODP) AND SENSING METHOD</th><th colspan="4">OIL PUMP/SYSTEM TYPE</th></tr>
<tr><th>NO OIL PUMP</th><th>OIL PUMP RUNS AT START-UP ONLY</th><th>CONTINUOUSLY RUNNING OIL PUMP</th><th>DEMAND OIL PUMP</th></tr>
<tr><td>[1]ODP1 by differential pressure switch</td><td colspan="2">Oil-to-suction ΔP</td><td>Oil-to-discharge ΔP</td><td>Oil-to-suction ΔP</td></tr>
<tr><td>ODP1 by transducers</td><td colspan="2">Oil injection pressure – Suction pressure</td><td>Oil injection pressure – Discharge pressure</td><td>Oil injection pressure – Suction pressure</td></tr>
<tr><td>ODP2 by differential pressure switch</td><td rowspan="2">Not used</td><td>Oil-to-discharge ΔP (during start-up only)</td><td colspan="2" rowspan="2">Not used</td></tr>
<tr><td>ODP2 by transducers</td><td>Oil injection pressure – Discharge pressure (during start-up only)</td></tr>
</table>

[1]Designated ODPS on applications with no oil pump or a continuously running oil pump (only one oil differential pressure switch fitted).

Table 4 Summary of Differential Pressure Sensing

7.2. Oil Differential Pressure 1 (ODP1)

No oil pump or oil pump runs at start-up only

When the compressor starts, the suction/discharge pressure differential must rise to establish oil flow and an oil differential pressure in excess of the ODP1 value.

After allowing sufficient time for the pressure differential to rise ODP1 is brought into the trip circuit. If the pressure differential has not exceeded the ODP1 value, or falls below the ODP1 value during operation, the compressor stops and a trip is displayed.

Continuously running oil pump

On starting the compressor and oil pump, the oil pressure differential must rise to establish oil flow and an oil differential pressure in excess of the ODP1 value.

After allowing sufficient time for the pressure differential to rise, ODP1 is brought into the trip circuit. If the pressure differential has not exceeded the ODP1 value, or falls below the ODP1 value during operation, the compressor and oil pump stop and a trip is displayed.

Demand oil pump

For demand oil pump operation system pressures are monitored by a J & E Hall International Fridgewatch 2000 Controller.

The demand oil pump starts a few seconds before the compressor. After the minimum run time interval expires, Fridgewatch checks if system pressure difference is sufficient to maintain adequate oil supply without the oil pump running. If Fridgewatch decides that the oil pump is not required, the pump is stopped, otherwise the pump continues to run until system pressure difference increases.

Once the pump has stopped, Fridgewatch continues to monitor oil injection pressure. If as a result of falling system pressure difference, oil injection pressure approaches the ODP1 trip value, the pump is restarted.

7.2.1. Oil Flow Switch

For applications without an oil pump or with a continuously running oil pump, the oil differential pressure switch can be replaced by a flow switch positioned in the oil line to the compressor bearings.

Contacts close at 0.15 litres/second on flow increase.
Contacts open at 0.095 litres/second on flow decrease.

On starting the compressor, oil flow must rise to a value in excess of the flow switch contacts close value.

After allowing sufficient time for oil flow to rise, the flow switch is brought into the trip circuit. If oil flow has not exceeded the contacts close value, or falls below the contacts open value during operation, the compressor stops and a trip is displayed.

7.2.2. Oil Differential Pressure 2 (ODP2)

This differential pressure is only applicable when the oil pump runs at start up only.

Before the compressor starts, the start-up oil pump runs to establish a discharge/oil pump pressure differential in excess of the ODP2 value.

After allowing sufficient time for the pressure differential to rise, ODP2 is brought into the trip circuit. If the pressure differential has not exceeded the ODP2 value, the start sequence is terminated and a trip displayed.

For applications with separate solenoid valves in the oil feed and oil injection lines, ODP2 continues to be monitored all the time the compressor is running.

7.2.3. Oil System Differential Pressure Drop

Gauges or pressure transducers must be provided to measure the pressure differential across the oil system, including the oil filter.

Oil pressure drop across filter	=	Oil pressure before oil filter	-	Oil pressure after oil filter

NOTE: do not allow the pressure drop across the filter to exceed the clean filter pressure drop plus 1.4 bar, before changing the filter element.

7.2.4. Maintaining Discharge Pressure at Start up

Because oil pressure is generated by suction/discharge pressure differential, there is a minimum discharge pressure value which must be maintained in order to ensure adequate and reliable oil flow.

In circumstances where the minimum discharge pressure is difficult to achieve, even with the help of condenser head pressure control devices, a differential pressure regulator must be fitted in the discharge line immediately after the oil separator. Fig 9 illustrates a typical arrangement using a Danfoss PM 1 main valve and CVPP pilot valve.

Discharge pressure, inlet pressure to the main valve, is applied to the space below the pilot valve diaphragm. Suction pressure is applied via a pilot line to the space above the diaphragm. The main valve, therefore, controls on the differential between suction and discharge pressure.

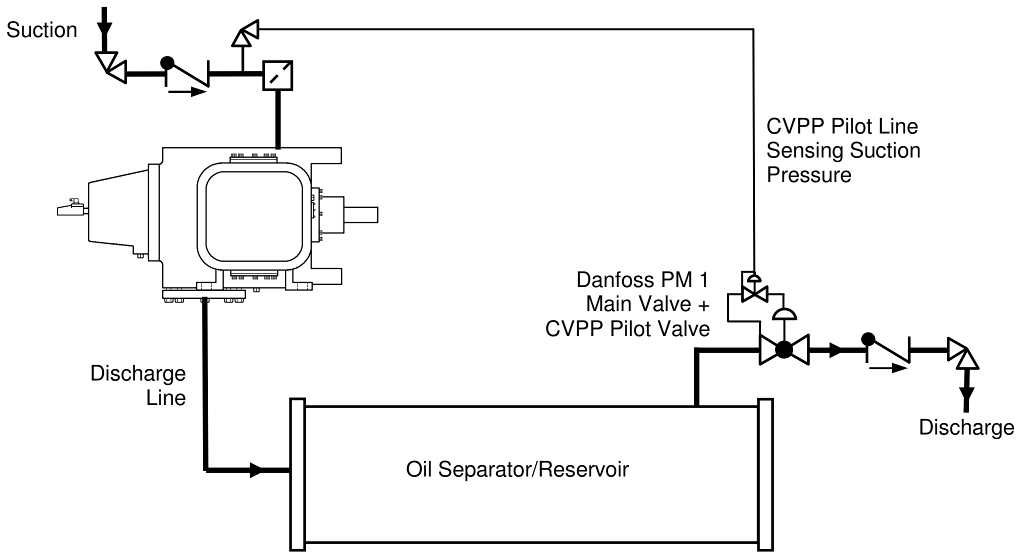


Fig 9 Maintaining Discharge Pressure at Start up

The differential pressure regulator allows discharge pressure to build up quickly on starting to achieve the necessary oil differential pressure before the start delay time expires (usually 30 seconds). If the suction/discharge pressure differential falls below the minimum requirement to maintain adequate oil flow, the pilot valve throttles the main valve to maintain the differential pressure, thereby ensuring adequate oil flow to the compressor. During normal operation the main valve will usually be fully open with little detrimental effect on compressor performance.

7.3. Oil Filter

To ensure minimum wear on moving parts and to maximise bearing life it is essential to fit an adequately sized oil filter; the location of the filter is shown in Appendix 2 Oil Support System Schematic Flow Diagrams.

The oil filter should be of the type that uses a disposable element and must be compatible, in all respects, with oil/refrigerant mixtures. A bypass must **NOT** be included in the filter assembly.

The filter element should be capable of filtering to 10 microns or better ($\leq 10\mu$). A typical filter specification would be $\beta 25 \geq 75$, $\beta 10 \geq 3$, $\beta 5 > 1$. This specification indicates that the filter element will pass 1 particle in 75 of 25 micron size, 1 particle in 3 of 10 micron size and will provide some measure of filtration of 5 micron particles. Due to the refrigerant absorbed in the oil, the filter element must be sized to give a lower pressure drop than would otherwise be normal, i.e. 0.35 bar g maximum, with the oil flow rates shown in Table 3. Remember that at certain operating conditions, a continuously running oil pump will be required; refer to Appendix 3 Limits of Operation Envelopes.

The maximum permissible pressure drop across the complete oil system, with the oil filter fitted with a clean filter element, should not exceed 2.0 bar. During operation, change the filter element if the pressure drop across the oil filter exceeds the clean filter pressure drop, plus 1.4 bar.

7.4. Compressor Cooling

The heat of compression must be removed either by the evaporation of liquid refrigerant injected directly into the compression process (liquid injection), or by using an external heat exchanger to cool the oil injected to seal the compression process.

For further details refer to publication 2-122 Compressor Cooling.

7.5. Lubricating Oils

The choice of lubricant depends on the refrigerant, the type of system and the operating conditions.

As choosing the correct lubricant is essential for compressor reliability and optimum system performance, this issue is discussed in detail in publication 2-59 Lubricating Oils.

8. Prolonged Storage

In certain cases, it may be necessary to keep the compressor in store for several months before installation and commissioning takes place. In this event, the following precautions should be taken.

8.1. Placing the Compressor into Store

(a) The store area must be weatherproof, well ventilated, warm and dry.

It is not recommended to transport or store the compressor where vibration from adjacent machinery may be present as this can be a contributory factor in the 'Brinelling' (fretting corrosion) of the bearing tracks and rolling elements. The method of packing the compressor for storage is of great importance, using any method that may help to reduce play between the bearing elements. Rubber blocks or pads introduced under the compressor mounting feet are very helpful in dampening out external vibrations and should be fitted whenever possible.

NOTE: the above precautions are equally applicable to other items of equipment fitted with rolling element bearings, for example, drive motors and pumps.

During the time in store, it is very important that the compressor mainshaft is not rotated as this will tend to remove the film of grease protecting the gland seal faces, described in step (b), below.

(b) To prevent damage to the gland seal faces, these surfaces should be lightly greased before the compressor is placed in store.

If the compressor drive half coupling is already fitted, this must be removed from the mainshaft. Purge the holding charge of nitrogen from the compressor.

Dismantle the gland assembly and lightly grease the seal faces. The correct grade of grease to use is Aviation Grease No 14DID5609, Specification: Aviation Grease No 14 DEF STAN 91/81-1 (available from J & E Hall International – part number 6764-102).

NOTE: grease is applied to the gland seal faces to keep the two surfaces apart during storage as prolonged stationary contact may cause molecular bonding between the carbon faces, resulting in damage to the seal when the compressor is started.

Reassembly the gland. Re-evacuate the compressor to a pressure of 2 mm Hg absolute, or lower, and charge with dry nitrogen to a pressure above atmospheric (0.7 bar g to 1 bar g); this will prevent ingress of air and moisture which can result in oxidation. Check for leaks.

NOTE: the film of grease between the two gland seal faces will not necessarily produce a perfect seal and a pressure higher that that recommended may force the grease from between the faces. Even at this low pressure a leak may occur but provided that this is not excessive the inert atmosphere within the compressor will be maintained.

At the end of the period in store, the protective grease must be removed and the sealing faces inspected for damage prior to installing and running the compressor; refer to 8.2. Taking the Compressor out of Storage.

(c) Suitably protect the compressor mainshaft extension from moisture and external damage by coating the shaft with Shell Enis Fluid MD or a thin film of grease, then covering with a plastic or rubber sleeve. External fittings, if any, should also be protected from damage.

(d) Leak test the compressor at frequent intervals to ensure that it retains the holding charge of nitrogen; refer to the **NOTE** in step (b). If pressure gauges are fitted these can be checked for a decrease.

(e) Carry out any special instructions for the long term storage of the compressor drive motor (if supplied); refer to the manufacturer's instructions.

8.2. Taking the Compressor out of Storage

At the end of the period in store, the following procedure should be adopted before the initial start in order to minimise the possibility of damage.

NOTE: specially negotiated guarantee terms to cover 'stored compressors' will not be honoured unless these procedures are followed.

(a) Carefully purge the holding charge of nitrogen from the compressor.

NOTE: the holding charge of nitrogen must be removed before the compressor is run.

(b) Remove the protective sleeve from the compressor mainshaft extension. Clean off the grease or, if Shell Enis Fluid MD was used, use white spirit or similar solvent to remove the protective film.

(c) Dismantle the gland assembly. Carefully clean the protective grease from the seal faces. If the faces are in a satisfactory condition they should be lightly oiled and the gland reassembled; if they are damaged, a new seal must be fitted.

(d) If necessary, refit the compressor drive half coupling.

(e) Finish installing the compressor as described under 9. Installing the Compressor.

Protecting the gland seal faces with grease can result in the gland needing rebedding-in, and might therefore, leak a small amount during the running-in period.

9. Installing the Compressor

The following instructions apply to 'bare' compressors; adapt as necessary if the compressor forms part of a package unit.

If the compressor has been in prolonged storage, carry out the instructions described under 8.2. Taking the Compressor out of Storage, before installation takes place.

9.1. Lifting the Compressor

Attach lifting tackle to a pair of eyebolts (full thread) screwed into the compressor suction/discharge flange face as shown in Fig 10. A crane or block and tackle will be required to lift the compressor. Check that the lifting equipment is stout enough to take the weight by referring to Appendix 1 Compressor Data.

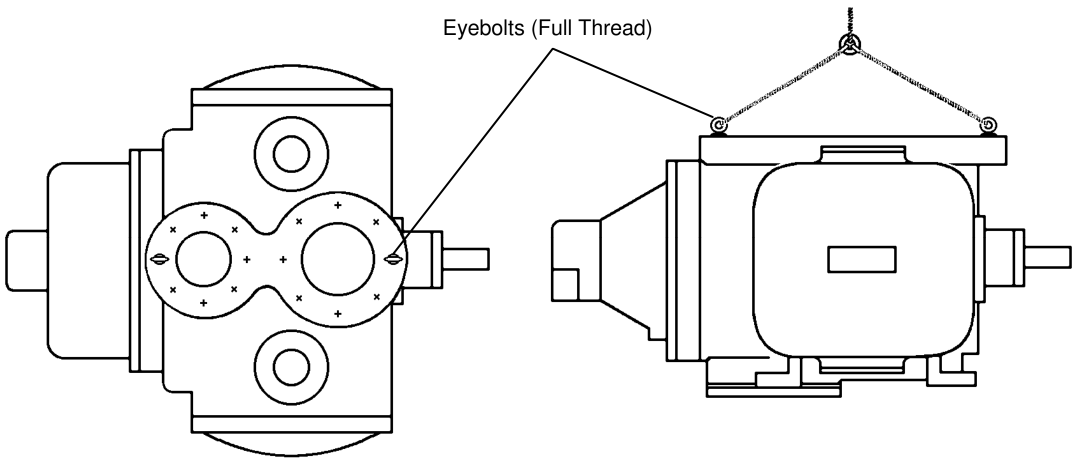


Fig 10 Lifting the Compressor

Check that the compressor mounting points on the baseframe are completely free from rust, dirt or burrs. Lift the compressor and make the same check on the underside of the compressor's four mounting feet.

As the compressor is being positioned, insert the holding-down bolts through the mounting feet into the baseframe. When all four bolts are in position, set the compressor down on the baseframe and remove the lifting gear. Screw the nuts onto the holding-down bolts and tighten

⚠ CAUTION

To prevent the nuts working loose during operation, use nuts with nylon inserts (stiff nuts) or secure with Loctite thread sealer.

9.2. Making Connections

Pipeline connection sizes are detailed in Appendix 1 Compressor Data.

(a) Carefully purge the holding charge of nitrogen from the compressor.

NOTE: the holding charge of nitrogen must be removed before the compressor is run.

(b) If the economiser facility is to be used, remove the blanking plugs from the economiser connections. Connect the economiser lines to the ports.

(c) If the compressor is fitted with liquid injection cooling, connect the liquid supply line to the flanged connections on the main casing.

(d) Before running the compressor, the moving parts must receive some initial lubrication.

- Remove the blank plug(s) or flange(s) from the oil injection connection(s), remove the blank plug from rear main bearing oil connection. Inject oil to lubricate the mainshaft bearings, main rotor flutes, star rotors and star rotor bearings.
- Remove the blank plug from the gland housing and inject oil to lubricate the gland seal assembly.
- Remove the blank plugs from the capacity control cylinder connections, these are positioned at the top of the casing and are marked 'Load' and 'Unload'. Use these connections to fill the capacity control cylinder with oil.

It is important to be fairly generous with this initial lubrication, using in all about 2 litres of oil. Use the same type and ISO grade of oil as that used in the rest of the system.

(e) Connect the oil injection lines, and the lube oil lines to the gland and rear main bearings.

(f) Connect the lines supplying oil from the capacity control solenoid valves to the capacity control cylinder 'Load' and 'Unload' connections.

(g) Connect the suction and discharge lines, and suction, discharge and oil pressure gauge lines.

(h) Rotate the mainshaft by hand to ensure that the motion-work turns smoothly and evenly.

If the compressor proves very stiff to turn, turns unevenly, or rotation is accompanied by any unusual noise, contact J & E Hall International.

(i) Connect the drive between the compressor and the prime mover. If the drive coupling is supplied by J & E Hall International, refer to publication 2-79 for drive installation and alignment details.

⚠ WARNING

The drive coupling MUST be protected by a suitable FIXED coupling guard.

(j) Make electrical wiring connections as described in 9.3.

(k) Leak test and evacuate the system.

Leak testing and evacuation are described in the following publications available from J & E Hall International:

- Part D : Strength and Leak Testing.
- Part E : Evacuation and Dehydration.

9.3. Electrical Wiring Connections and Interlocks

The following electrical connections are required to the compressor:

- Mains electrical supply to the compressor drive motor and motor starter. Refer to the motor and starter manufacturer's instructions.
- Electrical supply to the capacity control solenoid valves; refer to Fig 3 and Fig 4.

  If a 4-way solenoid valve is used; refer to publication 4-45 available from J & E Hall International.
- Electrical supply to the capacity control slide valve position transducer; refer to 4.8. MSI Linear Variable Displacement Transducer (MSI LVDT).
- Electrical interlock to prevent the compressor starting unless the slide valves are at minimum load; refer to 4.1.1.

10. Commissioning and Operation

If the compressor is supplied as part of a package unit supplied by J & E Hall International, refer to Section 1 of the plant instruction manual for detailed installation and commissioning instructions.

The instructions included in this part of the manual cover bare-shaft compressors supplied for incorporation into package units or site erected systems.

NOTE: these procedures cover the most important points for consideration and do not in any way supersede instructions for the operation of specific plant.

10.1. Checks Prior to the First Start

Before the first start, or when recommissioning after a maintenance period, there are a number of important checks to be undertaken in addition to the normal pre-start routine when the compressor is in commission.

10.2. General Checks

(a) Check that the compressor package unit is firmly installed on its foundations and all piping and wiring connections have been made.

(b) If the economiser facility is to be used , check the blank plug has been removed from each economiser port; refer to 9.2. Making Connections.

(c) Check incoming main supply cables and fuses are correctly sized; refer to the wiring diagrams supplied.

(d) Check that the compressor package unit is correctly earthed. Depending on circumstances, this may require the installation of a separate earthing system.

(e) Check electrical connections for tightness. All interlock and external wiring should be in accordance with the wiring diagrams supplied.

(f) Check wiring for continuity and earth leakage. Ensure wiring is restored correctly after testing.

⚠ CAUTION

DO NOT, under any circumstances, carry out a high voltage test (Megger test) on:

- The discharge high temperature thermistor protection circuit, otherwise the thermistor will be damaged. Thermistors for high temperature protection may also be fitted in the compressor drive motor windings and/or oil injection/lubrication line.
- Any part of the control system containing semi-conductor devices.

(g) Check the electrical operation of all pressure controls, temperature controls and solenoid valves, using a multi-meter or test-lamp.

Pressure and temperature controls are set at approximately the required setting before leaving the factory.

(h) Check that the compressor discharge high temperature thermistor has a resistance of approximately 100 Ω and is neither open circuit or a short circuit.

Repeat this check for thermistors that may be fitted in the compressor drive motor windings and/or oil injection/lubrication line.

(i) Check that stop valves isolating pressure gauges, cut-outs or other pressure controls are fully open. These valves should be locked-open using circlips or equivalent locking devices.

10.3. Compressor Drive Motor

The following general checks are applicable. Also refer to the motor manufacturer's instructions.

(a) Check the supply voltage and comply with the motor manufacturer's data (usually stated on the motor data plate), and any difference in voltage does not exceed 3 % between any two lines. Since an imbalance produces a dramatic rise in the temperature of the motor windings, it is important that any imbalance is kept to a minimum.

Check and record the control supply voltage, this should be within 5 % of the design voltage.

NOTE: never attempt to run the compressor drive motor with an electrical supply voltage, frequency or phase rotation other than as designated on the motor electrical data plate.

(b) The compressor drive motor must **NOT** be started unless it is completely dry. If a moisture indicator is fitted this can be checked to ensure the motor is dry.

If the motor is fitted with anti-condensation heater(s), these must be energised at least 24 hours before running the motor for the first time.

If there is any doubt whether the motor has been affected by moisture, the value of the motor insulation resistance must be checked. The motor should not be run if the insulation resistance exceeds the minimum specified by the motor manufacturer, refer to the manufacturer's instructions.

NOTE: the practice of running a motor having low insulation resistance on full voltage is not recommended. Insulation breakdown may occur before the windings dry out.

(c) Check that the motor cooling air intakes are not obstructed, permitting free air flow with no recirculation. This is particularly important if the motor is of the closed circuit, air-cooled type.

10.4. Checking Compressor Rotation

(a) The HallScrew compressor is a positive displacement machine designed to rotate in one direction only, this is anticlockwise when looking on the drive end of the compressor main shaft.

To prevent incorrect compressor rotation, it is **ESSENTIAL** to check the rotation of the compressor drive motor with the coupling disconnected.

The various safety controls can also be tested while the motor is running.

(b) Isolate the electrical supply to prevent the compressor accidentally starting.

Remove the coupling guard. Disconnect the drive coupling by removing the membrane/spacer unit.

Refit the coupling guard so that the rotation of the motor can be safely observed.

(c) Switch on the drive motor and check the direction of rotation. When looking on the end of the motor drive shaft the shaft should turn in a clockwise direction.

(d) With the motor running, check that all safety controls operate at their correct settings and stop the drive motor.

(e) Stop the motor and isolate the electrical supply to prevent it accidentally restarting.

Remove the coupling guard. Rotate the compressor mainshaft several times, by hand, to check that the motion-work turns smoothly and evenly.

(f) Check the drive alignment, adopting the method described in publication 2-79 in Section 2. If the alignment is out, check the baseframe is level and not distorted, or the compressor package unit is not under excessive strain from the various pipe connections.

Refit the membrane/spacer assembly and coupling guard.

10.5. Lubrication System

(a) Check that the oil separator/reservoir is filled to the correct level. This precaution will prevent any delay in oil reaching the compressor on starting.

If the compressor is fitted with a remote water-cooled or air cooled oil cooler, check the cooler is filled with oil.

(b) The oil separator/reservoir heaters must be energised at least 24 hours before the initial start to ensure that the oil is warm.

An oil temperature of approximately 45 °C is about right.

If the heaters are thermostatically controlled, the thermostat should be set to maintain the desired oil temperature.

NOTE: the oil heaters must NOT be energised without first of all checking that the oil reservoir has been charged with oil as described in step (a). Failure to take this precaution may result in the heaters burning-out.

The oil heaters must be electrically interlocked to energise during the off-cycle (compressor stopped).

(c) Check that the stop valves in the oil circulating system are fully open except, of course, drain and purge valves which open to atmosphere.

(d) If the system is fitted with an oil pump, start-up or continuously running, start the pump and check it rotates in the correct direction.

Check and, if necessary, set the oil differential pressure regulator to relieve at 2.5 bar to 3.0 bar.

Stop the oil pump.

10.6. First Start

(a) Check that the oil in the reservoir is warm enough (the heaters should have been energised 24 hours before the first start to ensure this). An oil temperature of approximately 45 °C is about right.

If an oil heater thermostat is fitted, the thermostat should maintain the oil at the correct temperature.

(b) Open the suction and discharge stop valves.

⚠ WARNING

The compressor must NEVER be started with the discharge stop valve closed or partially closed, nor must the discharge stop valve be throttled when the compressor is running.

(c) If liquid injection oil cooling is fitted, check that stop valves are open in the line supplying refrigerant to the liquid injection valve. With the solenoid valve in the line energised (open), the sight-glass in the line should be full of refrigerant.

Check that the stop valves in the the rest of the refrigeration system are in their correct running positions.

(d) If the plant is fitted with a water cooled oil cooler, start the water circulation pump and check for adequate flow through the cooler.

(e) Check the following:

- Safety devices and interlocks are in a 'safe' condition.
- Auxiliaries which are required to run before the compressor starts, for example, the condenser water pump and/or evaporator cooled medium pump, are providing interlock 'running' signals to the control system.

(f) For safety reasons, select hand compressor start/stop - hand capacity control operating mode for starting the compressor for the first time and for the initial period of operation.

(g) Start the compressor.

The following descriptions refer to applications using oil differential pressure switches to sense system pressures.

No Oil Pump

After the compressor has started and been in operation for a short time, allowing sufficient time for the system pressure differential to become established, ODPS is brought into circuit. Oil is now being supplied to the compressor under the action of the system pressure differential monitored by ODPS. If the system pressure differential falls below the switch contacts open setting, ODPS will trip and stop the compressor motor.

Start-up Oil Pump

The oil pump starts before the compressor.

When sufficient oil pressure differential is available between the oil reservoir outlet and the pump delivery, i.e. at least 1.5 bar, contacts of ODPS2 close allowing the compressor start sequence to proceed. After the compressor has started and been in operation for a short time, allowing sufficient time for the system pressure differential to become established, the oil pump is stopped and ODPS2 electrically bypassed. At the same time ODPS1 is brought into circuit. Oil is now being supplied to the compressor under the action of the system pressure differential monitored by ODPS1. If the system pressure differential falls below the switch contacts open setting, ODPS1 will trip and stop the compressor motor.

Continuously Running Oil Pump

The oil pump and compressor start together.

Providing the drain line is clear of oil, the oil pump and compressor start together. ODPS is brought into circuit after allowing sufficient time for the oil pump to start and contacts of ODPS to close. ODPS will stop the compressor unless the oil differential pressure has risen to 1.5 bar during the start period, and continues to monitor this differential all the while the plant is in operation.

Demand Oil Pump

The demand oil pump, controlled by the Fridgewatch 2000 Controller, enables the system to run for most of the time without an oil pump, but if system pressure difference falls the oil pump runs as necessary. For a full description of operation refer to the instruction manual for the Fridgewatch 2000 Controller, available from J & E Hall International.

(h) Monitor the compressor discharge temperature. Either use a ‘touch’ thermometer on the discharge line or, for a more accurate reading, use a wire temperature probe taped to the line; the probe can be left in-situ. Continue to monitor the discharge temperature during the commissioning period.

If the compressor is fitted with cooling by liquid injection, with the compressor in operation the solenoid valve in the liquid injection line energises (opens) allowing refrigerant to enter the injection line. Check the sight-glass positioned in the line to the injection valve is full of liquid refrigerant. Observe the liquid injection valve opens when the discharge temperature rises to approximately 75 °C. Adjust the injection valve if required, however, final adjustment must wait until after charging has been completed and the compressor is running at design conditions.

If the compressor is fitted with a water-cooled oil cooler, adjust the water valve at the cooling water outlet to give an oil temperature of 40 °C. If automatic flow regulation is not fitted, a manual valve must be throttled to achieve the correct temperature.

If the compressor is fitted with a remote air cooled oil cooler, adjust the device controlling the air flow (fan speed control, dampers etc.,) to give an oil temperature of 40 °C.

(i) Check that the oil separator/reservoir heaters de-energise when the compressor motor starts.

(j) Calibrate the LVDT 4 to 20 mA slide valve position signal for maximum and minimum load; refer to 4.8. MSI Linear Variable Displacement Transducer (MSI LVDT).

(k) Check that safety devices, the HP and LP cut-outs for example, and all external safety interlocks trip and stop the compressor.

(l) Adjust the capacity control oil flow control valves as described in 4.3.4. or 4.4.4. Flow Control Valves.

(m) Run-in the compressor; refer to 11. Running-In the Compressor.

10.7. Normal Starting and Running

(a) Check the oil level in the oil reservoir. The sight-glass should show an oil level equal to the standing level when the plant is not operating.

Check that the oil in the reservoir is warm enough (the heaters should have been energised 24 hours before the first start to ensure this). An oil temperature of approximately 45 °C is about right.

If an oil heater thermostat is fitted, the thermostat should maintain the oil at the correct temperature.

(b) Check all pressure gauge valves and transducer or cut-out isolating valves are open.

(c) Stop valves throughout the system must be in their correct positions for running, this is particularly important regarding the compressor suction and discharge stop valves.

⚠ WARNING

The compressor must NEVER be started with the discharge stop valve closed or partially closed, nor must the discharge stop valve be throttled when the compressor is running.

Check that the stop valves in the rest of the refrigeration system are in their correct running positions.

(d) If the plant is fitted with a water-cooled oil cooler, start the water circulation pump and check for adequate flow through the cooler.

(e) Begin the compressor start sequence.

(f) After the plant has started and operating conditions have stabilised, check and record temperatures, pressures and flow rates throughout the system.

(g) When shutting down the plant for any length of time, it is advisable to close the suction and/or discharge stop valves, together with the stop valve(s) in the oil feed lines. Make sure that stop valves are opened as required before restarting.

NOTE: in the case of prolonged shutdown periods, the procedures described under 13.5.9. Prolonged Shutdown should be followed.

10.8. Adding Oil to the System

If the compressor is fitted to a package unit supplied by J & E Hall International, the method of adding oil to the system is described in the plant instruction manual; refer to Section 1 Part H : Operation.

Oil added to the system must be fresh, clean oil of the same type and ISO grade as that already used in the system.

Acid test all oil before adding it to the system; even new oil has been known to fail this test. Refer to Table 7.

Spare oil for use in the plant should always be kept in properly closed containers. Exposure to atmosphere for extended periods may result in the oil becoming contaminated with dirt and/or moisture which can cause harmful reactions in the system. For similar reasons, oil reclaimed from the system should not be reused.

NOTE: these precautions are particularly important with polyolester synthetic lubricants which are very hygroscopic.

11. Running-In the Compressor

These procedures are carried out during the plant's first 200 hours of operation. Depending on circumstances, this time period may need to be extended.

11.1. Filters and Strainers

Refrigerant tends to have a scouring effect on the internal surfaces of the system. Despite the utmost care taken during manufacture, dirt, scale, grit and other extraneous material are released, especially during the early life of a new plant. It is essential not to add to the dirt burden, which is why attention to cleanliness is so important during installation and erection.

Apart from the compressor suction strainer (see next heading), change filters and clean strainers at the end of 200 operating hours; refer to 11.1. Filters and Strainers.

11.2. Compressor Suction Strainer

To prevent an excessive accumulation of dirt in the suction strainer, which would reduce the compressor's pumping efficiency, it is important to remove and clean the strainer basket during the plant's initial period of operation; suggested intervals are after 12 compressor operating hours and again at the end of 200 hours. If the strainer is partially choked with dirt when first cleaned, indicating that the system is particularly dirty, an additional cleaning after 100 hours may be necessary.

If the suction strainer has provision to fit a felt filter or separate suction filter, it is recommended to use this additional cleaning aid for the first 100 compressor operating hours.

After the commissioning period, clean the suction strainer annually, or at intervals of 5,000 operating hours, whichever is the sooner.

11.3. Oil Filter

Renew the oil filter element at the end of 200 compressor operating hours. If the system is very large or particularly dirty, it may be necessary to fit a new filter element before 200 operating hours are completed.

The pressure drop across the oil filter is a good indicator as to the condition of the filter element. If the oil filter pressure drop exceeds the clean filter pressure drop plus 1.4 bar, change the element.

11.4. Refrigerant Filter/Drier

Not usually applicable to plants charged with ammonia (R717), applicable to all other refrigerants.

Renew the filter/drier cores at the end of 200 plant operating hours. If available, cores having high acid retention properties should be used.

11.5. Monitoring for Moisture

Not usually applicable to plants charged with ammonia (R717), applicable to all other refrigerants.

Check the refrigerant sight-glass/moisture indicator on a regular basis during the first 12 plant operating hours, and occasionally over the next 100 hours. If there is evidence of moisture, immediate steps must be taken to remove the moisture by changing the filter/drier cores. In any case, fit new cores at the end of the first 200 operating hours.

11.6. Lubricating Oil

At the end of the first 200 compressor operating hours, drain off a sample of oil for analysis. Unless there is evidence of excessive contamination, there is no need to change the oil at this time.

Check the oil level in the oil separator/reservoir on a regular basis, preferably once every day.

***Not** applicable to plants charged with ammonia (R717), applicable to all other refrigerants.*

During the running-in period, as oil is distributed throughout the system, it may be necessary to add extra oil from time to time until the overall oil content has stabilised. Afterwards, it should only be necessary to replace the small quantity of oil lost during maintenance exercises, for example, changing the oil filter element.

Applicable to plants charged with ammonia (R717), ***not*** *applicable to other refrigerants.*

Unless the system is fitted with an oil still which automatically returns oil to the separator/reservoir, it is usually necessary to manually drain oil from vessels in the LP side of the system (suction separator, flooded evaporator or plate heat exchanger). If there is very little oil to drain, this period can be extended.

11.7. Checking for Leaks

Check the plant daily during the first week or two of operation for leakage of refrigerant or oil; thereafter check for leaks weekly.

11.8. Compressor Drive Motor Coupling

After the first 12 hours of compressor operation, stop the plant and remove the guard from the drive coupling. Remove the coupling membrane/spacer assembly.

Check the tightness of the ®Taper Lock bush grubscrews securing the compressor half-coupling, check the half-couplings have not slackened-off their shafts.

Check and record the distance between shaft ends (DBSE) and the drive alignment. The half-couplings should be aligned within 0.125 mm when using dial test indicators on each face and around the circumference. Refit the membrane/spacer assembly and the coupling guard.

Recheck and record the DBSE and drive alignment after approximately the first 200 operating hours.

11.9. Compressor and Drive Motor Holding-Down Bolts

After approximately the first 200 compressor operating hours, check the tightness of the nuts securing the compressor and motor holding-down bolts.

12. Pumping Down and Opening Up the Compressor

⚠ WARNING

Before opening up any part of the system, all personnel concerned must be aware of the potential hazards involved. Because safety is such an important topic, personnel should be thoroughly acquainted with the principles laid down in Safety.

On various occasions it will be necessary to open up part of the system for routine maintenance and inspection. It may also be necessary to dismantle the compressor for overhaul, in the event of mechanical failure.

If a mechanical failure is suspected within the compressor, proceed to 12.3. Isolating the Electrical Supply, omitting the pumping down procedure.

NOTE: do not attempt to run the compressor if a mechanical failure is suspected.

12.1. Preparing for Pump Down

As there is no stop valve fitted between the compressor and the discharge outlet from the oil separator, pumping down the compressor includes the oil separator as well.

Differences in plant layout, with particular reference to the position of pipe line stop valves, means that it is impossible to give precise instructions for every installation. However, the following method of pumping down the compressor and recovering the remaining refrigerant charge is generally applicable where suction and discharge stop valves are provided.

Close the discharge gauge valve and disconnect the gauge line. Connect a suitably sized refrigerant recovery unit to the gauge valve connection. If the system uses ammonia refrigerant, the recovery unit must be compatible for operation with this primary refrigerant.

12.2. Pumping Down the Compressor

NOTE: ensure that the cooled medium flow through the evaporator and the evaporating temperature are both adequate to prevent freezing in the evaporator during pump down.

Start and run the compressor.

It is desirable to reduce the capacity of the compressor as much as possible when pumping down. Turn the capacity control switch to the minimum load position and, using the load and unload push-buttons, move the capacity control slide valves to minimum load.

Slowly close the suction stop valve until the LP cut-out trips and stops the compressor. Fully close the suction stop valve as the compressor stops. Close the discharge stop valve after the compressor has stopped, together with the stop valves in all other pipe line connections to the compressor (for example liquid injection, oil injection, lubrication, capacity control).

NOTE: do not bypass the LP cut-out to achieve a lower suction pressure. This practice may ultimately result in marginal compressor lubrication conditions if excessive amounts of oil are pumped over.

12.3. Isolating the Electrical Supply

After pumping down the compressor, isolate the electrical supply to the control panel(s) and drive motor.

⚠ WARNING

Withdraw the fuses from the motor starter and keep them on your person so that they cannot be accidentally refitted, place a warning notice on the panel next to the main isolator. Disconnect the electrical supply to the compressor drive motor.

12.4. Removing the Residual Refrigerant Gas

Using the refrigerant recovery unit, transfer the remaining gas into approved storage containers. Each vessel to receive the refrigerant should be mounted on a suitable weighing device to ensure that the rated capacity of the vessel is not exceeded, taking into account the lower density of the oil/refrigerant mixture compared with pure refrigerant.

NOTE: do not mix different grades of refrigerant in the same recovery vessel. Each vessel should be used for only one grade of refrigerant.

When the suction pressure has fallen to approximately 0.75 bar abs, stop the recovery unit to allow the dissolved refrigerant to separate out from the oil. It may be necessary to run the recovery unit two or three times before it is possible to pump down to approximately 0.3 bar abs.

When as much gas as possible has been recovered from the compressor, close the discharge gauge valve connection and stop the refrigerant recovery unit.

Isolate and disconnect the refrigerant recovery unit and allow air to enter the compressor via the gauge valve.

12.5. Opening up the Compressor

Before opening up, drain off any oil left behind in the compressor.

⚠ WARNING

If the system uses R717 (ammonia) refrigerant, oil drained from the compressor may contain traces of ammonia. The compressor will certainly contain some residual ammonia which the recovery unit could not remove.

For protection against escaping ammonia the operator should wear protective clothing, goggles and a suitable respirator.

Removing the side covers gives access to the star rotors and the main rotor, removing the discharge end cover gives access to the capacity control mechanism. Carry out the necessary maintenance and/or inspection as required.

NOTE: when working on the compressor, great care must be taken to keep all components clean and prevent dirt from entering. Rags used for cleaning must be lint-free. If the compressor has to be left open for any length of time, covers should be refitted and any other openings blanked off to prevent the ingress of moisture, dirt or other foreign matter.

Reassemble the compressor using the original or replacement components. New gaskets, ‘O’ rings and a new oil filter element must be used.

12.6. Re-instating the Compressor

Reunite the compressor with the rest of the system by cracking open the discharge stop valve, before opening the suction stop valve.

Open the stop valves in all other pipe line connections to the compressor (for example liquid injection, oil injection, capacity control).

Check all joints for tightness, then check for leaks on the compressor and any other items disturbed during the maintenance operation.

Once the leak test has proved satisfactory, evacuate and dehydrate the compressor and all other parts of the system open to atmosphere. Adopt the procedures described in publication Part E : Evacuation and Dehydration, available from J & E Hall International.

Reconnect the electrical supply to the compressor motor. Make sure all wiring is restored in accordance with the original arrangement as shown on the plant wiring diagrams.

Replace the mains fuses and reinstate the power supply.

Recommission the compressor; refer to 10. Commissioning and Operation.

13. Maintenance

Routine maintenance is essential for the optimum availability and performance of all mechanical equipment, however, in this respect, refrigeration plant is in a somewhat different category since it is particularly susceptible to the presence of air and moisture inside the system. Consequently, it is undesirable to open up any part of the system on more occasions than is necessary to ensure efficient working.

13.1. Spare Parts

New parts must be suitable for use in the refrigeration environment. 'O' rings and gaskets, for example, must be compatible with the system refrigerant and lubricating oil.

As ammonia attacks copper, nickel, tin, zinc and cadmium, components containing these metals or their alloys are prohibited from ammonia refrigeration systems.

⚠ WARNING

The use of incompatible materials in an ammonia refrigeration plant can cause component failure and result in the release of large quantities of ammonia refrigerant.

Depending on the application, components may require the following certification:

- Material certification. The component is suitable for use with the system refrigerant, lubricating oil and secondary refrigerant (if used).
- Pressure test certification. The component is capable of withstanding the pressures likely to be encountered within the system.
- For plants located within the European Economic Area (EEC), components subject to pressure must, where necessary, be certified that they comply with the Pressure Equipment Directive (PED).
- Pressure relief devices require certification that they open at the set pressure and discharge at the required rate.

To ensure that the correct parts are supplied, manufactured from compatible materials and accompanied by all necessary certification, it is important to use spares obtained from J & E Hall International.

Obtain spare parts from the address below:

J & E Hall International
Hansard Gate,
West Meadows,
Derby,
DE21 6JN
England

Telephone: +44 (0) 1332-253400
Fax: +44 (0) 1332-371061
E mail: jehall.derby@dial.pipex.com
Website: www.jehall.co.uk

Always provide the J & E Hall International contract number and compressor serial number(s) when ordering spares; refer to Part A : Specification.

Refer to Appendix 4 HS 2000 Series Compressor Replacement Parts.

13.2. Filters and Strainers

Clean the compressor suction strainer at the end of the first 12 hours operation.

Change the compressor oil filter element and clean strainers at the end of the first 200 hours operation, then at the intervals specified in 13.4. Maintenance Schedule. Experience of running the plant may suggest that strainers require cleaning at shorter intervals.

Compressor suction line.
Compressor liquid injection line - *liquid injection cooling fitted.* Economiser (subcooler) line before the solenoid valve and thermostatic expansion valve - *if economiser fitted.*
Compressor discharge line - *if separate secondary oil separator fitted.*
Oil line before oil pump suction - *if continuously running or demand oil pump fitted.*
Oil filter in the oil line after the oil separator - *if no oil pump fitted.* Oil filter in the oil line before the oil pump suction - *if start-up oil pump fitted.* Oil filter in the oil line after the oil pump delivery - *if continuously running or demand oil pump fitted.*
Table 5 Filter and Strainer Locations

Filter and strainer locations for the compressor and oil support system are detailed in Table 5. Refer to the plant instruction manual for the location of filters and strainers in the refrigerant and cooled medium lines.

13.3. Running-in

At the end of the commissioning period, the running-in procedures, described under 11. Running-In the Compressor, must been carried out during the first 200 hours of operation.

After running-in has been completed, maintain the plant according to the schedule following.

13.4. Maintenance Schedule

According to Lloyds survey requirements, unless a specific problem arises, the HallScrew compressor should not need opening up until the first inspection after six years or 25,000 operating hours run have elapsed, whichever is the sooner. Maintenance during the guarantee period should be carried out by J & E Hall International, or our appointed service representative, unless specifically agreed to the contrary by written agreement with J & E Hall International.

This maintenance schedule refers to the compressor, the package unit with which it is associated, and generally to the rest of the plant. Reference is made to instruction publications which can be found in the J & E Hall International instruction manual for the plant.

13.5. Maintenance Intervals

Planned maintenance exercises are initiated at intervals of calendar months *or* compressor operating hours, whichever time period expires first.

13.5.1. Daily

(a) Check the level in the compressor package unit oil separator/reservoir.

__Not__ applicable to plants charged with ammonia (R717), applicable to all other refrigerants.

It should not be necessary to add large quantities of oil to the system, other than that necessary to replace the small amount lost during maintenance exercises.

Applicable to plants charged with ammonia (R717), __not__ applicable to other refrigerants.

If it is necessary to manually drain oil from vessels in the LP side of the system (suction separator, flooded evaporator or plate heat exchanger), it will be necessary to top up the level in the separator/reservoir to account for the oil drained off.

(b) Check and record system temperatures, pressures and flow rates.

The specimen log sheet illustrated in Appendix 5 Plant Performance Record shows the minimum number of readings which should be taken to enable an accurate assessment of the plant's performance to be made. In the case of a very large plant, many more readings need to be logged to complete the overall picture.

Particular attention should be paid to the following readings:

- Oil temperature measured at the oil cooler outlet (if an oil cooler is fitted instead of liquid injection).
- Oil pressure at the compressor oil injection connection.
- The net oil pressure drop across the oil filter.
- Suction and discharge pressures and temperatures.

Gauge and temperature readings should be checked regularly, in addition to routine logging, and any variations from normal promptly investigated.

13.5.2. Weekly

(a) Check the plant for refrigerant and oil leaks; refer to Leak Detection in the publication for the refrigerant in Section 5.

While checking for leaks, inspect the exterior of the plant for damage or corrosion.

(b) Check that capped valves have their caps firmly in position to prevent tampering, loss of refrigerant or the entry of air and moisture.

(c) Not usually applicable to plants charged with ammonia (R717), applicable to all other refrigerants.

Check the sight-glass/moisture indicator. If there is evidence of an increase in the moisture content of the system, corrective action must be taken immediately by changing the refrigerant filter/drier cores, and tracing and rectifying the cause of moisture ingress.

(d) Applicable to plants charged with ammonia (R717), not applicable to other refrigerants.

Unless the system is fitted with an oil still which automatically returns oil to the separator/reservoir, it is usually necessary to manually drain oil from vessels in the LP side of the system (suction separator, flooded evaporator or plate heat exchanger). If there is very little oil to drain, this period can be extended.

Turbulent conditions inside these vessels when the plant is operating tend to distribute the oil in droplet form throughout the body of liquid ammonia. It is necessary to stop the plant and wait for the oil to collect in the bottom of the vessel before draining off.

⚠ WARNING

The greatest care must be taken when using external drain valves. Protective clothing, gloves, goggles and a respirator must be worn.

(e) On multi-compressor applications, changeover the role of lead, lag and/or standby compressor.

13.5.3. Monthly

(a) Check the operation of the compressor capacity control system; refer to 4.8. MSI Linear Variable Displacement Transducer (MSI LVDT)

(b) If a secondary oil separator is fitted in the discharge line, check the pressure drop across the secondary oil separator. If the pressure drop exceeds 0.7 bar, change the filter elements.

13.5.4. Every Year, or at Intervals of 5,000 Operating Hours

(a) Pump down the compressor and isolate the compressor and oil separator/reservoir. The procedure to follow is described under 12. Pumping Down and Opening Up the Compressor.

(b) Take a sample of oil from the oil separator/reservoir. Preferably, send the sample to the oil supplier for laboratory analysis and report; the analysis must include checking the oil's acid content and moisture content. Alternatively, use an acid test kit, available from the manufacturer of the lubricating oil, to check that the acid content remains within the normal range for the oil.

For all plants *other* than those charged with ammonia (R717), record the acid content in Table 7.

If it is necessary to change the oil, drain off the oil charge from the oil separator/reservoir. Decant the old oil into empty drums and return it to the oil supplier/manufacturer for recycling. Do not forget to mark each drum with its contents.

Evacuate the oil separator/reservoir as described in Part E : Evacuation and Dehydration. Refill the reservoir with the correct quantity of fresh, clean oil of the same type and ISO grade as that already used in the system, using the vacuum in the reservoir to draw the oil into the vessel through the connection provided; refer to the plant schematic flow diagram.

(c) Renew the oil filter element(s).

It may be necessary to fit a new element before this interval/hours-run time expires if the oil filter pressure drop exceeds the clean filter pressure drop plus 1.4 bar.

(d) Clean strainers throughout the system; refer to Table 5.

Examine each strainer basket. If the mesh is damaged, torn etc., fit a new basket.

Experience of running the plant may suggest that more frequent cleaning is necessary.

(e) Not usually applicable to plants charged with ammonia (R717), applicable to all other refrigerants.

Renew the refrigerant filter/drier cores. Drier cores should be changed at earlier intervals if the cores become choked, or the amount of moisture in the system reaches a dangerous level. The sight-glass/moisture indicator will show evidence of contamination.

(f) Check that pressure and temperature controls operate correctly at the appropriate setting value.

(g) Remove the membrane/spacer assembly from the compressor drive coupling. Examine the membrane spigots closely for signs of cracking, fretting or other wear. If any damage is evident a new membrane/spacer assembly should be fitted.

Check and record the distance between shaft ends (DBSE) and the drive alignment before reconnecting the coupling.

- For details of the spacer drive coupling, including the method of checking the coupling alignment, refer to publication 2-79 in Section 2.

(h) After approximately the first 200 compressor operating hours, check the tightness of the fastenings securing the compressor and motor mountings.

(i) Check the condenser gauge temperature against the liquid refrigerant outlet temperature. If the presence of air or other non-condensable gas is suspected, carry out a full test and purge as required.

Check more frequently if operating conditions are such that the pressure in the suction line is below atmospheric.

13.5.5. Every 3 Years, or at Intervals of 15,000 Operating Hours

(a) Pump down the compressor and isolate the compressor and oil separator/reservoir. The procedure to follow is described under 12. Pumping Down and Opening Up the Compressor.

(b) Drain off the oil charge from the oil separator/reservoir. Decant the old oil into empty drums and return it to the oil supplier/manufacturer for recycling. Do not forget to mark each drum with its contents.

Oil separator with single stage oil separation.

Evacuate the oil separator/reservoir as described in Part E : Evacuation and Dehydration. Refill the reservoir with the correct quantity of fresh, clean oil of the same type and ISO grade as that already used in the system, using the vacuum in the reservoir to draw the oil into the vessel through the oil drain line.

Oil separator fitted with coalescing elements for two stage oil separation.

The oil separator/reservoir is fitted with coalescing elements. Remove the inspection cover situated at one end of the separator shell to gain access to the coalescing elements; these should be inspected for obvious signs of damage and renewed if necessary.

⚠ WARNING

The greatest care must be exercised when opening up the separator. Protective clothing, gloves, goggles and a respirator must be worn; refer to Safety Equipment in the publication for the refrigerant in Section 5.

If new coalescing elements are to be fitted, after removing the old elements, this opportunity should be taken to clean out the inside of the vessel; pay particular attention to the area around the outlet stub pipe. Refit the inspection cover using a new gasket if required.

Evacuate the oil separator/reservoir as described in Part E : Evacuation and Dehydration. Refill the reservoir with the correct quantity of fresh, clean oil of the same type and ISO grade as that already used in the system, using the vacuum in the reservoir to draw the oil into the vessel through the oil drain line.

(c) Renew the compressor drive coupling membrane/spacer assembly.

- For details of the spacer drive coupling, including the method of checking the coupling alignment, refer to publication 2-79 in Section 2.

13.5.6. Every 6 Years, or at Intervals of 25,000 Operating Hours

(a) Pump down the compressor and isolate the compressor and oil separator/reservoir. The procedure to follow is described under 12. Pumping Down and Opening Up the Compressor.

(b) Open up the compressor for inspection in the presence of J & E Hall International or our appointed representative.

Remove the side covers to reveal the stars, main rotor and capacity control slide valves; remove the discharge end cover to gain access to the capacity control mechanism.

13.5.7. Every 12 Years, or at Intervals of 50,000 Operating Hours

(a) Pump down the compressor and isolate the compressor and oil separator/reservoir. The procedure to follow is described under 12. Pumping Down and Opening Up the Compressor.

(b) Open up the compressor for inspection in the presence of J & E Hall International or our appointed representative.

Remove the side covers and examine the star shaft bearings and main bearings with a view to replacement. Renew if in any doubt.

Examine the stars. Renew if damaged or worn.

(c) Check the operation of the capacity control mechanism for 'drifting' from the required slide valve position. If 'drifting' is occurring and the capacity control solenoid valve(s) are in good condition and appear to be working correctly, renew the glide ring/'O' ring seal on the capacity control hydraulic piston.

13.5.8. Every 24 Years, or at Intervals of 100,000 Operating Hours

(a) Pump down the compressor and isolate the compressor and oil separator/reservoir. The procedure to follow is described under 12. Pumping Down and Opening Up the Compressor.

(b) Dismantle the compressor and check parts for damage or wear. Renew the main bearings.

13.5.9. Prolonged Shutdown

(a) If the plant is shutdown for an extended period, it is advisable to close the compressor suction and discharge stop valves. Make sure that stop valves are opened as required before restarting.

⚠ WARNING

The compressor must NEVER be started with the discharge stop valve closed or partially closed.

(b) It is important to run the plant for at least one hour each week. This short period of operation helps maintain components by ensuring that bearing surfaces are well lubricated, especially mechanical gland seals which might otherwise leak, and promotes trouble-free running when full-time operation resumes.

With sufficient oil pressure available, use the load/unload push-buttons to operate the compressor capacity control mechanism over the full length of its travel.

(c) The electrical system is arranged to ensure that heaters de-energise when the compressor starts and re-energise when the compressor stops.

If the plant has been electrically isolated long enough for the lubricating oil to cool down, the isolator(s) must be turned to the 'on' position and the oil separator/reservoir heaters energised to warm the oil before restarting. Wait until the oil temperature risen to approximately 45 °C, this ensures that any refrigerant absorbed by the oil is evaporated.

(d) If it is not possible to run the plant periodically during the prolonged shutdown period, contact J & E Hall International for recommendations on safe storage and long term preservation of the plant.

13.6. Maintenance Check List

Table 6 illustrates the maintenance schedule as a 'Check List'.

PARA	DAILY	✓
13.5.1	Check the oil separator/reservoir oil level.	
	Check and record system temperatures, pressures and flow rates.	
PARA	**WEEKLY**	✓
0	Check for leakage of refrigerant and oil. Inspect the exterior of the plant for damage or corrosion.	
	Check valve caps are in place.	
	Check the sight-glass/moisture indicator for the presence of moisture.- *not usually applicable to plants charged with ammonia (R717), applicable to all other refrigerants.*	
	Drain off any oil which has collected in the LP side of the system - *applicable to plants charged with ammonia (R717),* ***not*** *applicable to other refrigerants.*	
	On multi-compressor applications, changeover the role of lead, lag and/or standby compressor	
PARA	**MONTHLY**	✓
13.5.3	Check the compressor capacity control system operates correctly	
	Check the pressure drop across the secondary oil separator - *separate secondary oil separator fitted in the discharge line*	
PARA	**EVERY YEAR, OR AT INTERVALS OF 5,000 OPERATING HOURS**	✓
13.5.4	Check the condition of the system oil charge, renew if necessary	
	Renew the oil filter element.	
	Clean strainers throughout the system	
	Renew the refrigerant filter/drier cores - *not usually applicable to plants charged with ammonia (R717), applicable to all other refrigerants.*	
	Check pressure and temperature safety controls operate correctly	
	Check the condition of the coupling membrane/spacer assembly	
	Check the tightness of the nuts securing the compressor and drive motor holding-down bolts	
	Check for air in the system. Check more frequently if operating conditions are such that the pressure in the suction line is below atmospheric.	
PARA	**EVERY 3 YEARS, OR AT INTERVALS OF 15,000 OPERATING HOURS**	✓
13.5.5	Renew the system oil charge	
	Check the condition of the coalescing elements in the oil separator - *oil separator fitted with coalescing elements for two stage oil separation*	
	Renew the compressor drive coupling membrane/spacer assembly	
PARA	**EVERY 6 YEARS, OR AT INTERVALS OF 25,000 OPERATING HOURS**	✓
13.5.6	Remove side and end covers, inspect the compressor	
PARA	**EVERY 12 YEARS, OR AT INTERVALS OF 50,000 OPERATING HOURS**	✓
13.5.7	Examine the star bearings and main bearings. Renew if in doubt.	
	Examine the stars. Renew if damaged or worn.	
	Check the capacity control mechanism for 'drifting'	
PARA	**EVERY 24 YEARS, OR AT INTERVALS OF 100,000 OPERATING HOURS**	✓
13.5.8	Dismantle the compressor and check parts for damage or wear. Renew the main bearings.	
	REFERENCE TO OTHER MAINTENANCE SCHEDULES	
	Grease compressor drive motor bearings according to the motor manufacturer's instructions.	

Table 6 Maintenance Check List

13.7. Oil Acid Content Record

Plants charged with refrigerant other than ammonia (R717).

Each time the oil's acid content is checked, record the value in Table 7.

ACID CONTENT	SIGNATURE	PRINTED NAME	DATE

Table 7 Oil Acid Content Record - Plants Charged with Refrigerant *other* than Ammonia (R717)

Appendix 1 Compressor Data

- HSO 2000 Series: Compressor Model Nomenclature.
- HSO 2000 Series: Physical Data.
- HSO 2000 Series: Starting Torque Characteristics.
- HSO 2000 Series: Limits of Operation.
- Safety Requirements for Compressor Protection.
- HSO 2000 Series: Physical Dimensions and Connections.

HSO 2000 Series: Compressor Model Nomenclature

HallScrew	Application	Compressor			Capacity Control Slide V_R	Lubricant	Motor Power (Nominal)	Motor Voltage	Refrigerant	Voltage (Auxiliary)	Capacity Indicator	Stop Valves and Flanges	Economiser Kit	Discharge Thermistors
HS	O	2	0	X	X	X	X	X	X	X	X	X	X	X

Application	O	Open drive		
Compressor	20X	Series 2000 Twin Star 24, 28, 31 or 35		
Capacity Control Slide V_R	1	1.85 V_R		
	2	2.2 V_R		
	4	3.5 V_R		
	5	4.9 V_R		
	6	2.6 V_R		
Lubricant	E	Ester oil		
	M	Mineral oil		
Motor Power (Nominal)	0	Without motor		
Motor Voltage	0	No voltage (without motor)		
Refrigerant	A	R134a	F	R404a
	B	R22	G	R717
	C	R407c	H	R23
	D	R410a	X	Other
	E	R507a		
Voltage (Auxiliary)	0	No voltage		
Capacity Indicator	0	No capacity indicator (standard)		
	D	Capacity indicator (not self-setting)		
	E	Capacity indicator (not self-setting) plus signal conditioning module		
Flanges	G	Suction and discharge flanges, top suction (standard)		
	H	Suction and discharge flanges, bottom suction		
	I	Flanged mounted, bottom suction		
Economiser Kit	0	No economiser kit (standard)		
	1	Economiser kit		
	2	Liquid injection kit		
Discharge Thermistor	A	No discharge thermistor		

Example: HSO 2028/2/M/B

This describes a HallScrew 2028 twin star open drive compressor fitted with 2.2 V_R capacity control slide valves, supplied with mineral oil. Compressor for operation with R22.

HSO 2000 Series: Physical Data

Compressor Type	Single screw, open drive.
Compressor Rotation	Anticlockwise looking on the motor (driven) end. Under no circumstances should the compressor run in the reverse direction. For gas engine drive applications, an intermediate gearbox is required to reverse the rotation of the prime mover.
Method of Drive	Direct coupled to foot mounted drive motor.
Physical Dimensions	Refer to Physical Dimensions and Connections
Capacity and Power	Refer to selection data.
Capacity Control	Compressor capacity infinitely variable from 100 % to approximately 10 % of full load (depends on the operating conditions). Slide valve position indication by 4 to 20 mA Linear Variable Displacement Transducer (LVDT). DIN plug terminal box rating IP65.

Speed Ranges, Swept Volumes and Weights

Compressor	Normal Speed Range	Swept Volume (m^3/hr)		Max Allowable Shaft Power (kW)		Weight (kg)
		50 Hz	60 Hz	50 Hz	60 Hz	
HSO 2024	1450 to 3600 rpm	853	1024	250	300	449
HSO 2028		1273	1528	350	420	564
HSO 2031		1728	2074	460	550	810
HSO 2035	1000 to 3600 rpm	2486	2983	650	780	1194

[1]Sound Pressure Levels @ 50 Hz (2 pole speed)

Compressor	Total dB 'A'	NR	Centre Frequency - Hz					
			125	250	500	1 k	2 k	4 k
HSO 2024	84	82	71.5	82	80	82	73	69
HSO 2028	86	84	73	84	82	84	75	71
HSO 2031	88	86	75	86	84	86	77	73
HSO 2035	90	88	77	88	85	88	79	75

[1]Sound pressure level data applies to the compressor only. The sound pressure level for a standard air-cooled compressor drive motor is usually higher.

The data refers to free-field conditions at a distance of 1 metre from the compressor periphery. It is important to remember that on a specific installation the actual sound pressure level is considerably affected by the size and type of room, material of construction and plant design. Adjoining pipework, including suction, can have a very substantial effect on the noise level.

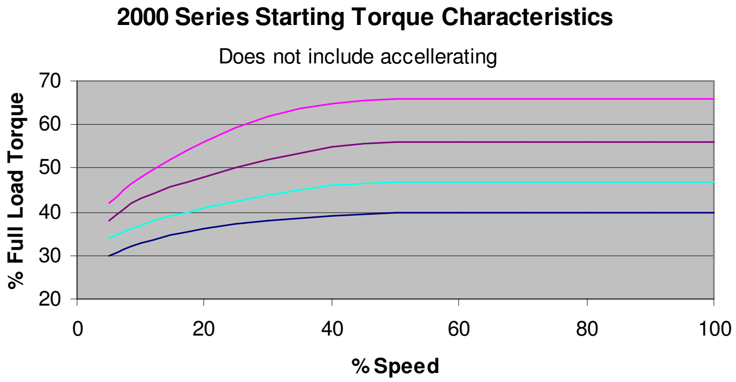
Sound pressure levels given in dB refer to 2×10^{-5} N/m^2 RMS.

HSO 2000 Series: Starting Torque Characteristics

Starting torque characteristics are shown for different system pressure ration, in tabular form and as a graph.

% Speed	% Full Load Torque			
	System Pressure Ratio			
	3	**5**	**10**	**15**
5	30	34	38	42
10	33	37	43	48
20	36	41	48	56
30	38	44	52	62
40	39	46	55	65
50	40	47	56	66
60	40	47	56	66
70	40	47	56	66
80	40	47	56	66
90	40	47	56	66
100	40	47	56	66

Does not include accelerating torque



Compressor Mass Moment of Inertia (MK^2)	
HSO 2024	0.34
HSO 2028	0.65
HSO 2031	1.06
HSO 2035	1.78

HSO 2000 Series: Limits of Operation

Pressure Limits	Detailed below are the test pressures applied to HallScrew compressors during the course of manufacture. These limits **MUST NOT** be exceeded during installation, commissioning or operation of the plant.	
Production	Compressor casing – strength Compressor casing – leak [1]Assembled compressor – strength Assembled compressor – leak	43.4 bar g 29.0 bar g 31.7 bar g 29.0 bar g
[2]Operational Pressure Limits	Design pressure (maximum working pressure)	29.0 bar g
	Maximum compressor operating suction pressure: Maximum compressor operating pressure differential (discharge – suction) Minimum suction pressure Maximum compressor ratio	V_R 2.2 and 3.0 = 6.0 bar g V_R 4.9 = 4.0 bar g 20.0 bar [3]See note 25:1
Temperature Limits	For normal refrigeration and air conditioning applications, the following temperature limits should be observed.	
[4]Compressors With External Oil Cooling	Discharge high temperature cut-out Lube oil high temperature cut-out Injected oil temperature	100 °C maximum 80 °C [5]40°C
[5.6]Compressors With Liquid Injection Oil Cooling (Standard)	[7]Controlled discharge temperature Discharge high temperature cut-out Injected oil high temperature cut-out	[8]75 °C 100 °C maximum 80 °C

[1]Assembled compressors MUST NOT be subjected to pressures higher than those indicated. This may require isolation of the compressor during system strength pressure testing.

[2]Oil separator pressure limits may be less than those applicable to the compressor.

[3]Refer to Appendix 3 Limits of Operation Envelopes.

[4]An oil cooling system MUST be fitted to all compressors. Part load operation will always require cooling even if full load operation does not.

[5]Injected oil temperature can be higher than 40 °C, allowing a smaller oil cooler to be used, provided the discharge and oil temperature limits are observed.

[6]If refrigerants other than R22, R717 (ammonia), R134a, R404a, R407c or R507A are used, consult J & E Hall International.

[7]If the controlled discharge temperature is likely to exceed 75 °C, a separate oil cooler is required to limit the temperature of the oil supply to the bearings, mainshaft gland seal and capacity control mechanism. Consult J & E Hall International.

[8]When operating at a condenser gauge above 50 °C, it is recommended that the discharge temperature is controlled to 25 °C above the condenser gauge to ensure satisfactory oil separation.

Safety Requirements for Compressor Protection

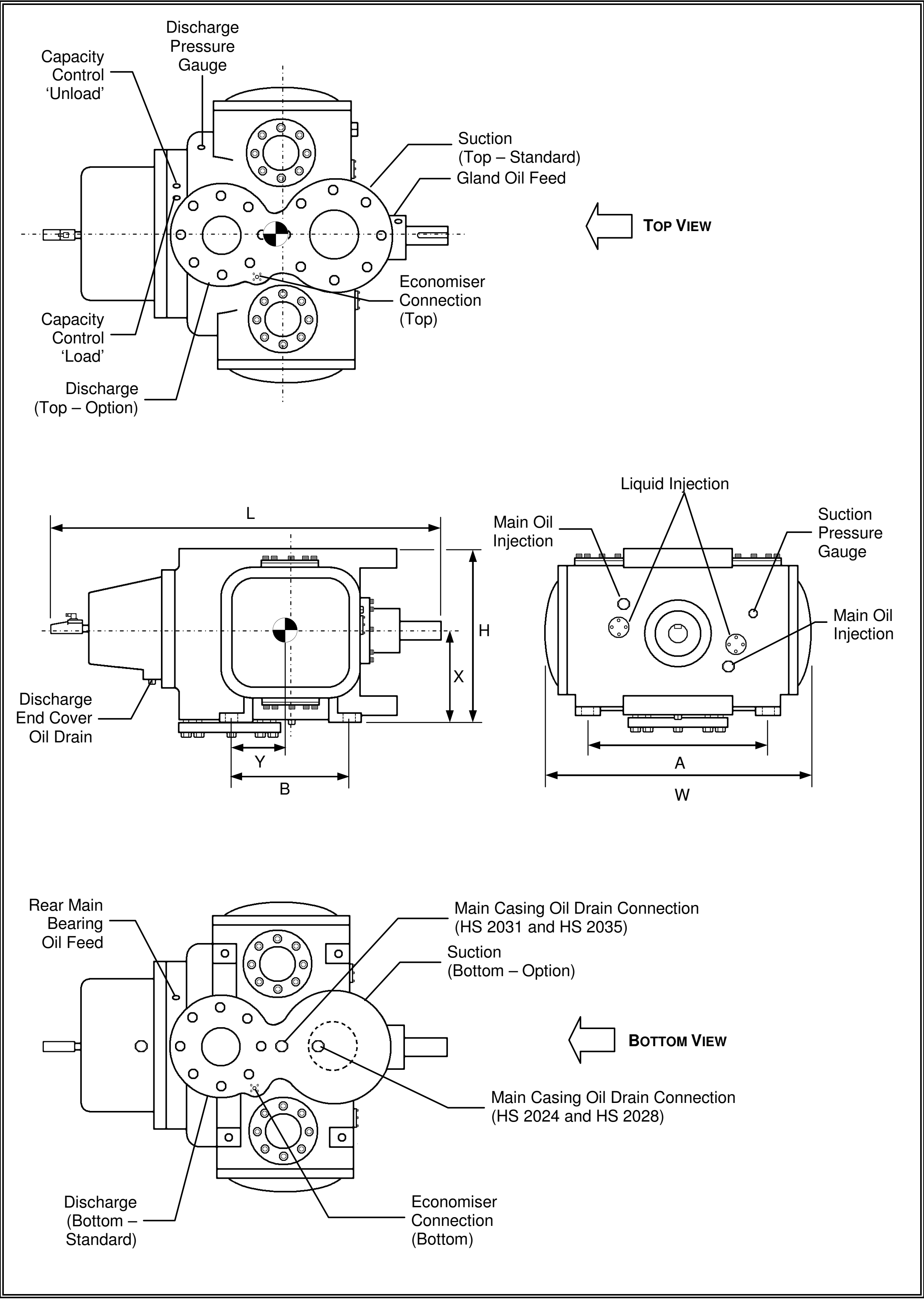
PARAMETER	TRIP	DEVICE	SETTING	REMARKS
Discharge pressure	High	HP cut-out	According to the operating conditions.	Connected to compressor discharge, refer to
[1]Discharge temperature	High	Cut-out or thermistor	100 °C	Temperature at the compressor discharge.
Suction pressure	Low	LP cut-out or pressure transducer and controller software programme	According to the operating conditions.	
Maximum compressor operating pressure differential (discharge - suction)	High	[2]Pressure operated main valve	According to the operating conditions.	-
Oil differential pressure	Low	Differential pressure switch or pressure transducers and controller software programme	Refer to Table 4.	
[1]Oil temperature	High	Cut-out or thermistor	80 °C	Temperature in oil line to compressor.
Oil flow	Low	Oil flow switch	Contacts close at 0.15 litre/second on flow increase. Contacts open at 0.095 litre/second on flow decrease.	For applications without an oil pump, the oil differential pressure switch can be replaced by a flow switch positioned in the oil lubrication line.
Oil separator oil level	Low	Level switch or sensor	Trip on low level.	Time delay required during operation to prevent spurious trips.
Oil drain line	-	Opto sensor	Trip if oil/liquid refrigerant present; refer to 6.2.1 Oil Drain Sensor.	Time delay required on starting, and during operation to prevent spurious trips.

[1]For high temperature applications consult J & E Hall International.
[2]Pilot operated main valve positioned in a bypass line connecting discharge and suction; refer to publication 2-123 available from J & E Hall International.

HSO 2000 Series: Physical Dimensions and Connections

Dimension[1]			HSO 2024	HSO 2028	HSO 2031	HSO 3035
Overall	Length	L	975	1130	1150	1305
	Height	H	446	500	560	640
	Width	W	714	780	888	1000
Centre of gravity		X				325
		Y				201.5
Holding-down bolt centres		A	420	470	600	660
		B	280	306	415	468
Holding-down bolt		-	4 x M22		4 x M26	
Lifting eyebolts[3]		-	1 x M20 1 x M24	2 x M24	2 x M24	2 x M24
Connection		**No Off**	**HSO 2024**	**HSO 2028**	**HSO 2031**	**HSO 3035**
Suction (top – standard, bottom – option)[2]		1	125 mm (5") NB BS 4504 Table 40/3. 8 x M24 on 220 PCD	150 mm (6") NB BS 4504 Table 40/3. 8 x M24 on 250 PCD	200 mm (8") NB BS 4504 Table 25/3. 12 x M24 on 310 PCD	
Discharge (bottom – standard, top – option)[2]		1	100 mm (4") NB BS 4504 Table 40/3. 8 x M20 on 190 PCD	125 mm (5") NB BS 4504 Table 40/3. 8 x M24 on 220 PCD	150 mm (6") NB BS 4504 Table 40/3. 8 x M24 on 250 PCD	
Suction pressure gauge		1	3/8" BSP x 6 mm OD male stud coupling			
Discharge pressure gauge		1	3/8" BSP x 6 mm OD male stud coupling			
Liquid injection		2	4 x M8 holes on 45 PCD (1/2 NB)			
Economiser		2	4 x M8 holes on 45 PCD (1/2 NB)			
Oil injection		2	3/4" BSP banjo bolt		1" BSP banjo bolt	
Gland oil feed		1	1/8" BSPT x 8 mm OD male stud coupling			
Rear main bearing oil feed		1	1/8" BSP x 8 mm OD male stud coupling			
Capacity control 'load'		1	1/8" BSP x 6 mm OD male stud coupling			
Capacity control 'unload'		1	1/8" BSP x 6 mm OD male stud coupling			
Main casing oil drain		1	3/4" BSP (plugged)		1" BSP (plugged)	
Discharge end cover oil drain		1	3/8" BSP (plugged)			

[1]Dimensions in mm unless otherwise stated. Data provided as a guide only, refer to J & E Hall International Limited certified drawing.
[2]Bottom suction and top discharge options must be clearly stated when ordering.
[3]Eyebolts screw into opposite tapped holes on main casing suction/discharge flange.


Discharge Pressure Gauge
Capacity Control 'Unload'
Suction (Top – Standard)
Gland Oil Feed
TOP VIEW
Economiser Connection (Top)
Capacity Control 'Load'
Discharge (Top – Option)
L
Liquid Injection
Main Oil Injection
Suction Pressure Gauge
Main Oil Injection
H
X
Discharge End Cover Oil Drain
Y
B
A
W
Rear Main Bearing Oil Feed
Main Casing Oil Drain Connection (HS 2031 and HS 2035)
Suction (Bottom – Option)
BOTTOM VIEW
Main Casing Oil Drain Connection (HS 2024 and HS 2028)
Discharge (Bottom – Standard)
Economiser Connection (Bottom)

Appendix 2 Oil Support System Schematic Flow Diagrams

Normally Open	Locked Open	Normally Closed	Normally Closed and Capped	
				Valve, straight through
				Valve, right angle

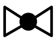
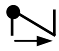
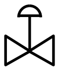
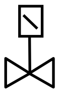
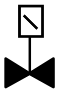
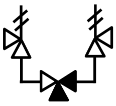
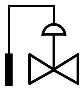
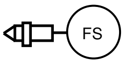
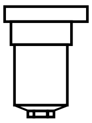
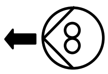
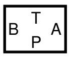
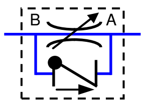
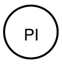
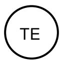
	Ball valve		Non-return valve
	Quick-acting drain valve, normally closed and capped		Control valve
	Relief valve		Solenoid valve (normally open)
	Relief valve (to atmosphere)		Solenoid valve (normally closed)
	Dual relief valve (to atmosphere)		Thermostatic expansion valve
	Sight-glass (on vessel)		Liquid drainer
	Sight-glass (in line)		Heater
	Strainer		Opto sensor in drain line
	Oil filter		Oil pump
	4-Way solenoid valve (subplate illustrated)		Flow control valve B → A = Full flow A → B = Metered flow
	Pressure Indication (pressure gauge or transducer)		Differential Pressure Switch
	Pressure Switch High (discharge high pressure cut-out or transducer)		Level Switch (opto sensor or level switch)
	Pressure Switch Low (suction low pressure cut-out or transducer)		Thermistor or high temperature cut-out

Fig 11 Key to Schematic Flow Diagrams

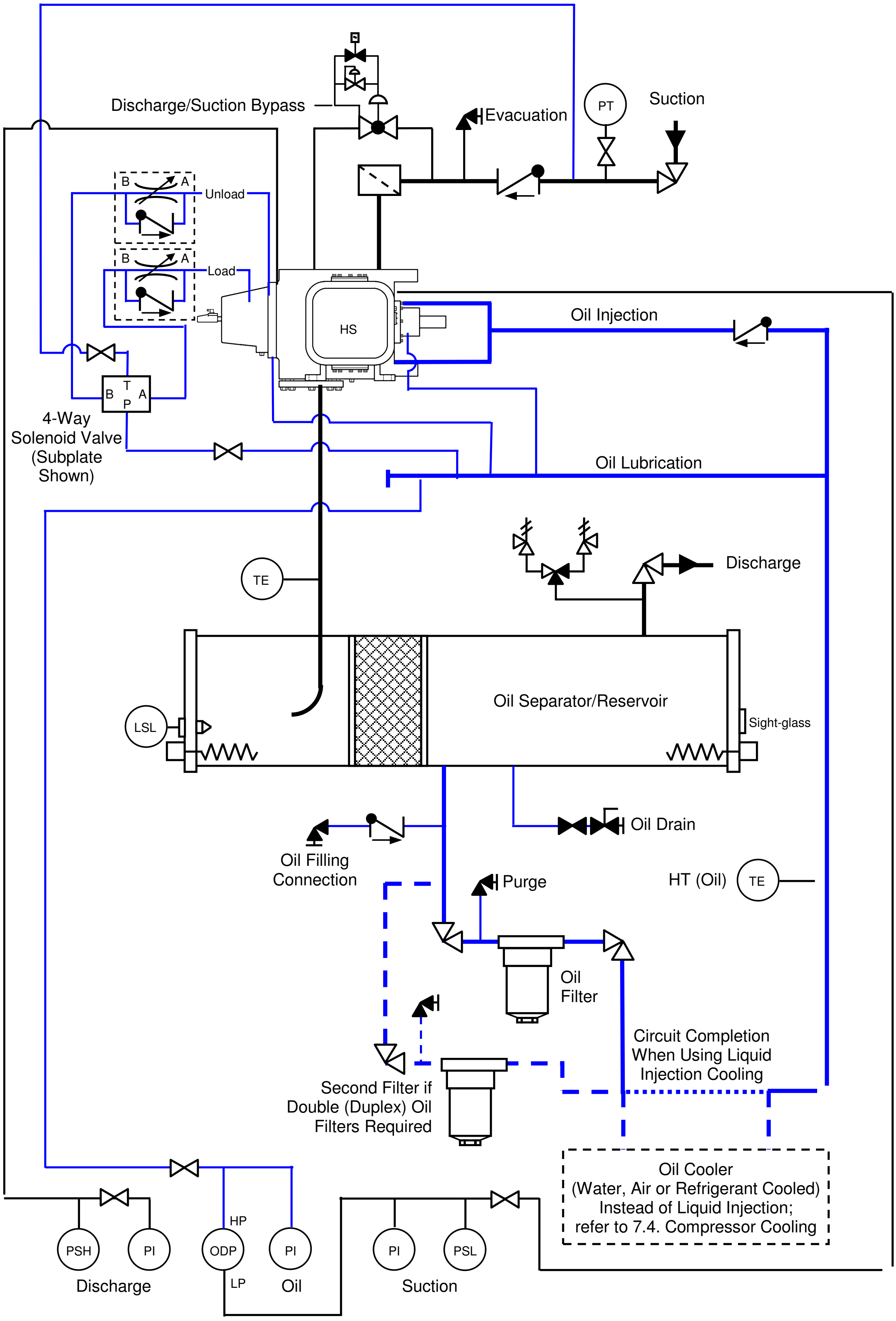


Fig 12 No Oil Pump

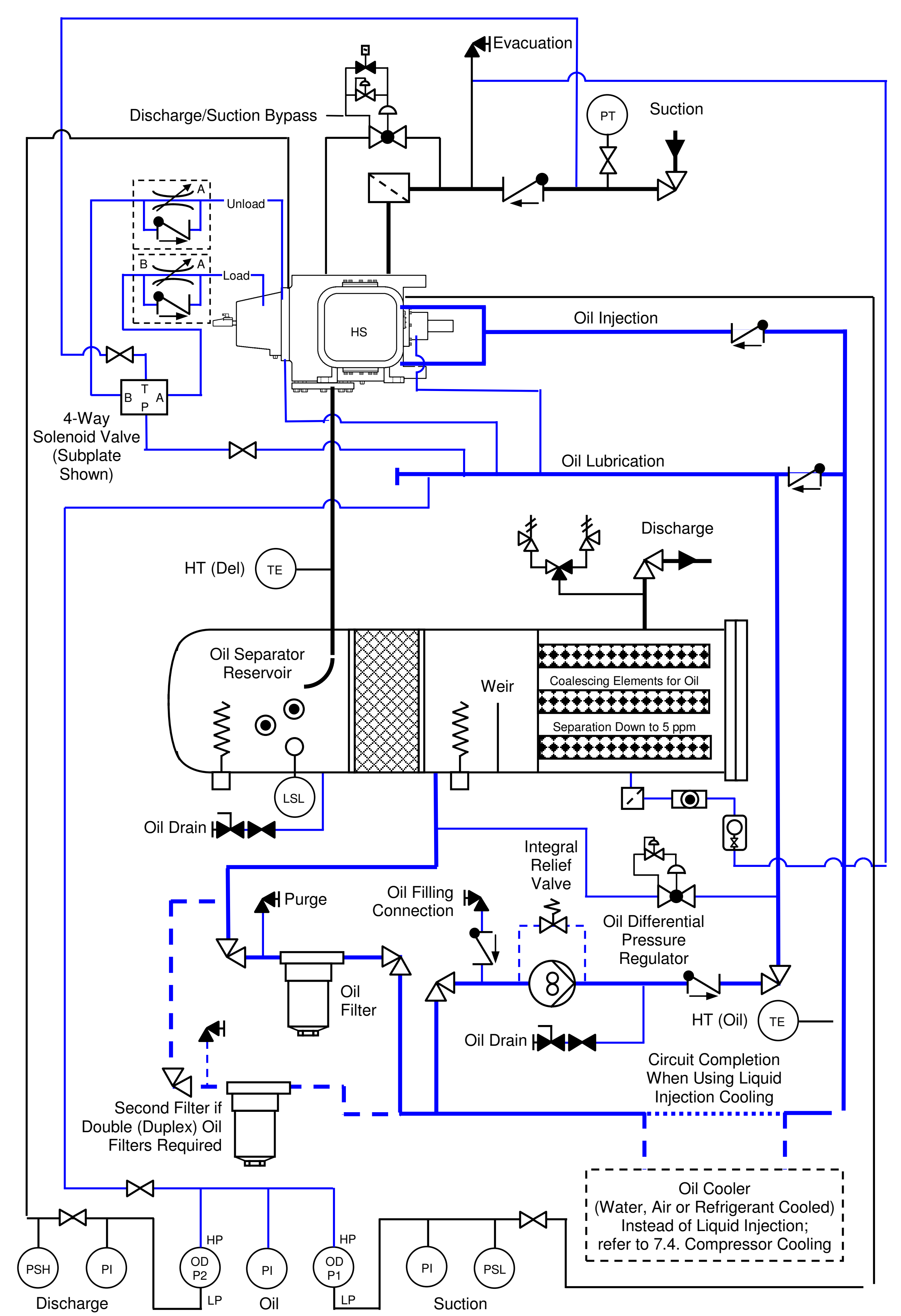


Fig 13 Start-up Oil Pump: Common Oil Lines for Injection and Lubrication

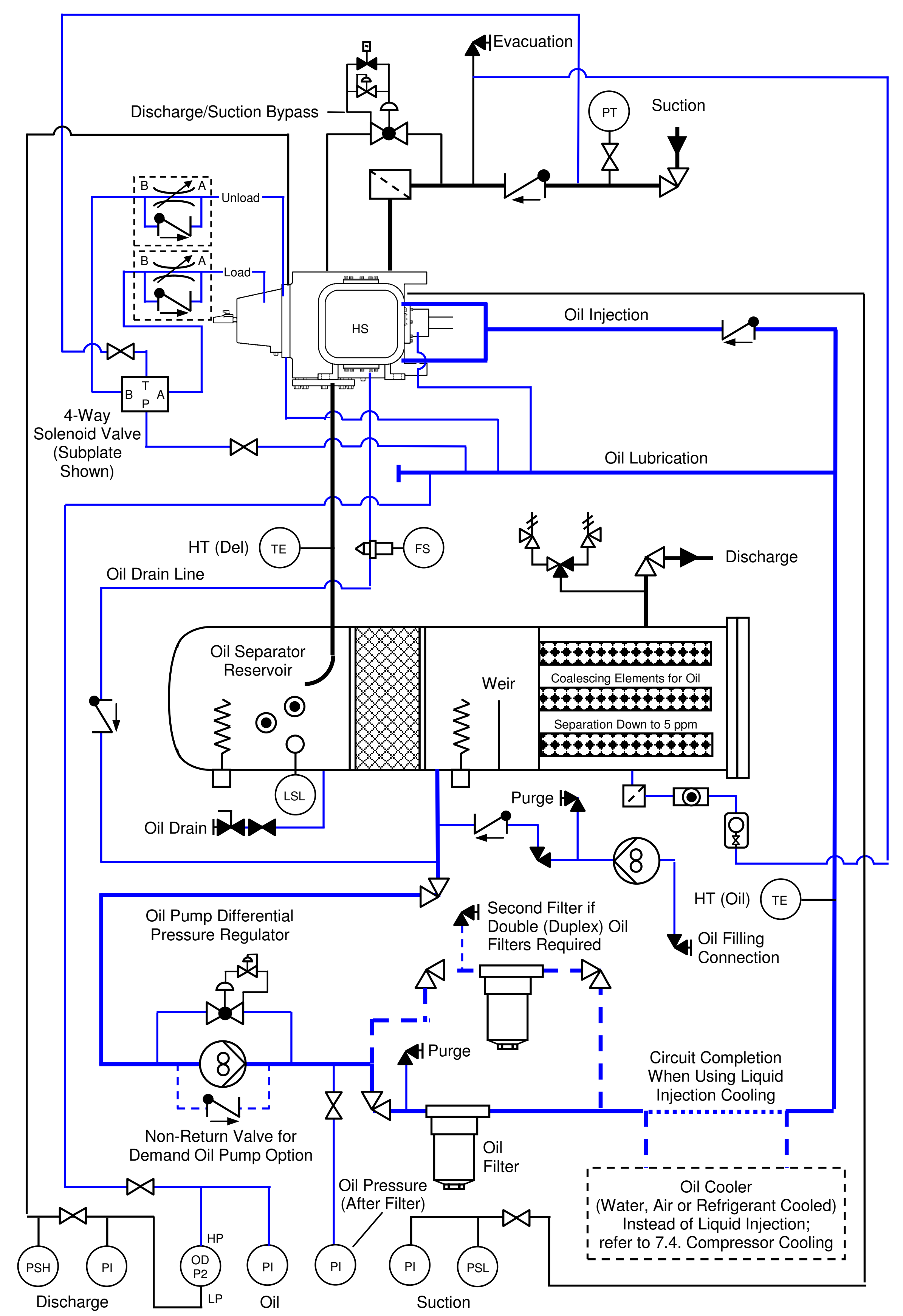
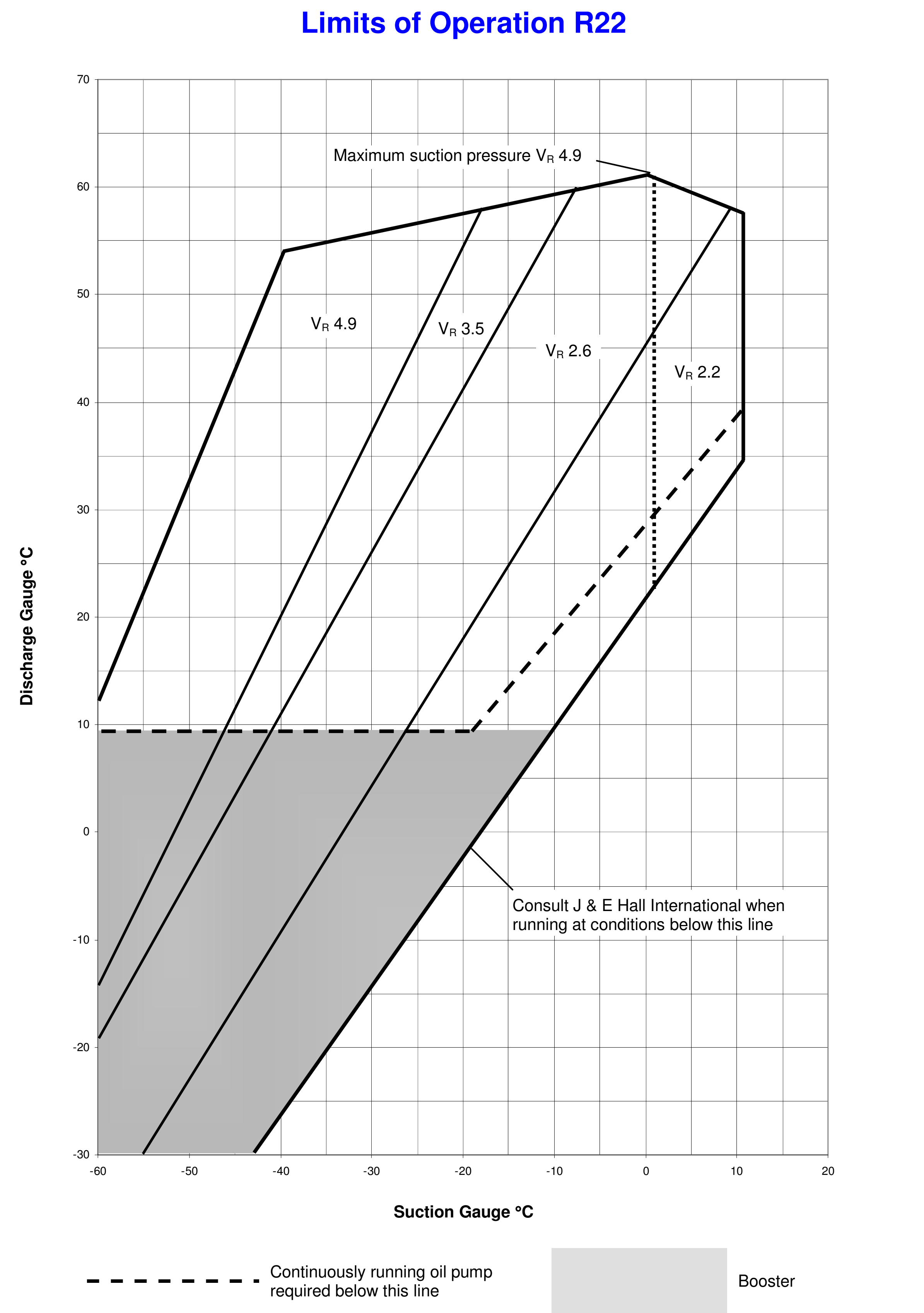


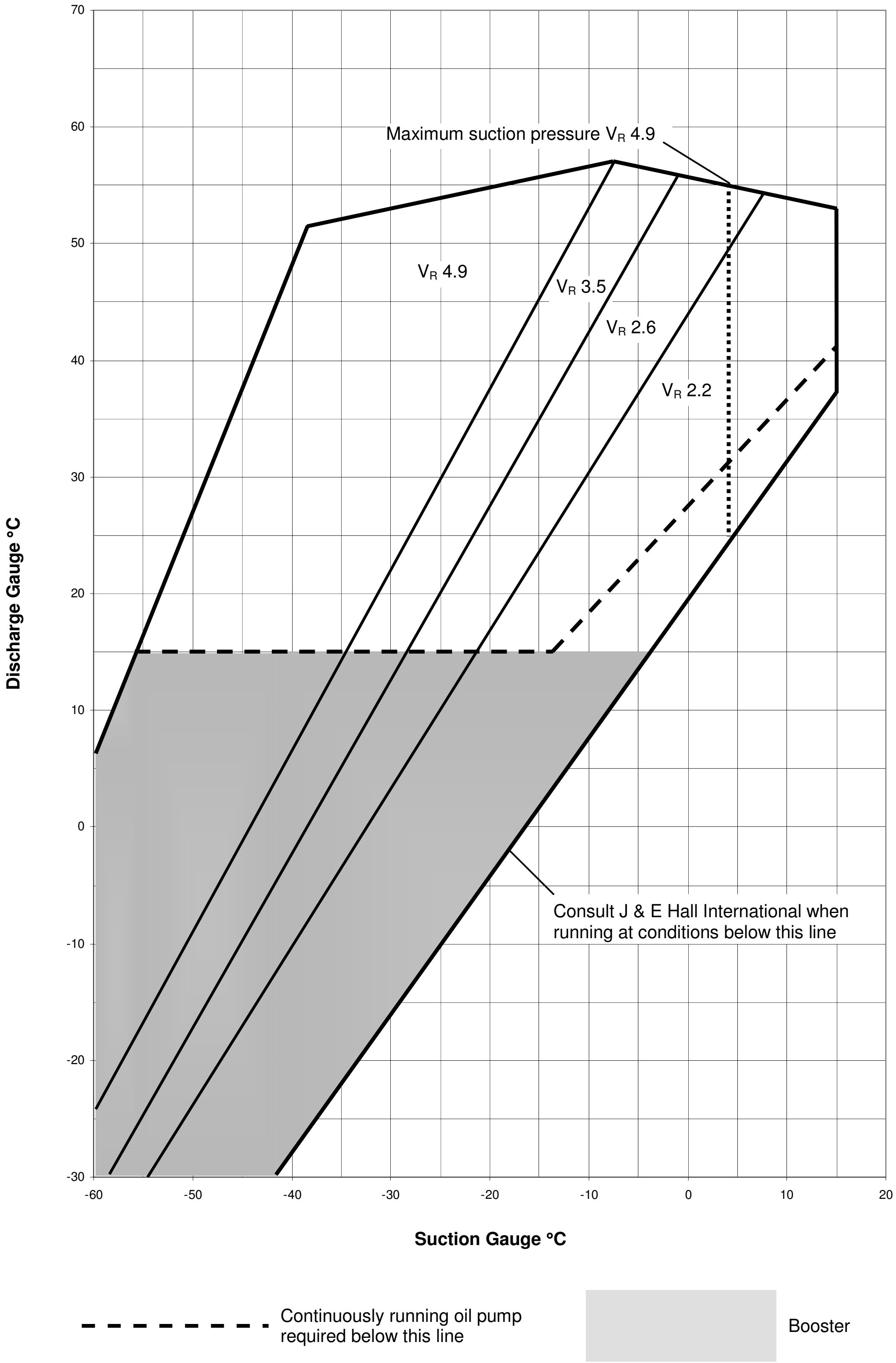
Fig 14 Continuously Running or Demand Oil Pump: Common Oil Lines for Injection and Lubrication

Appendix 3 Limits of Operation Envelopes



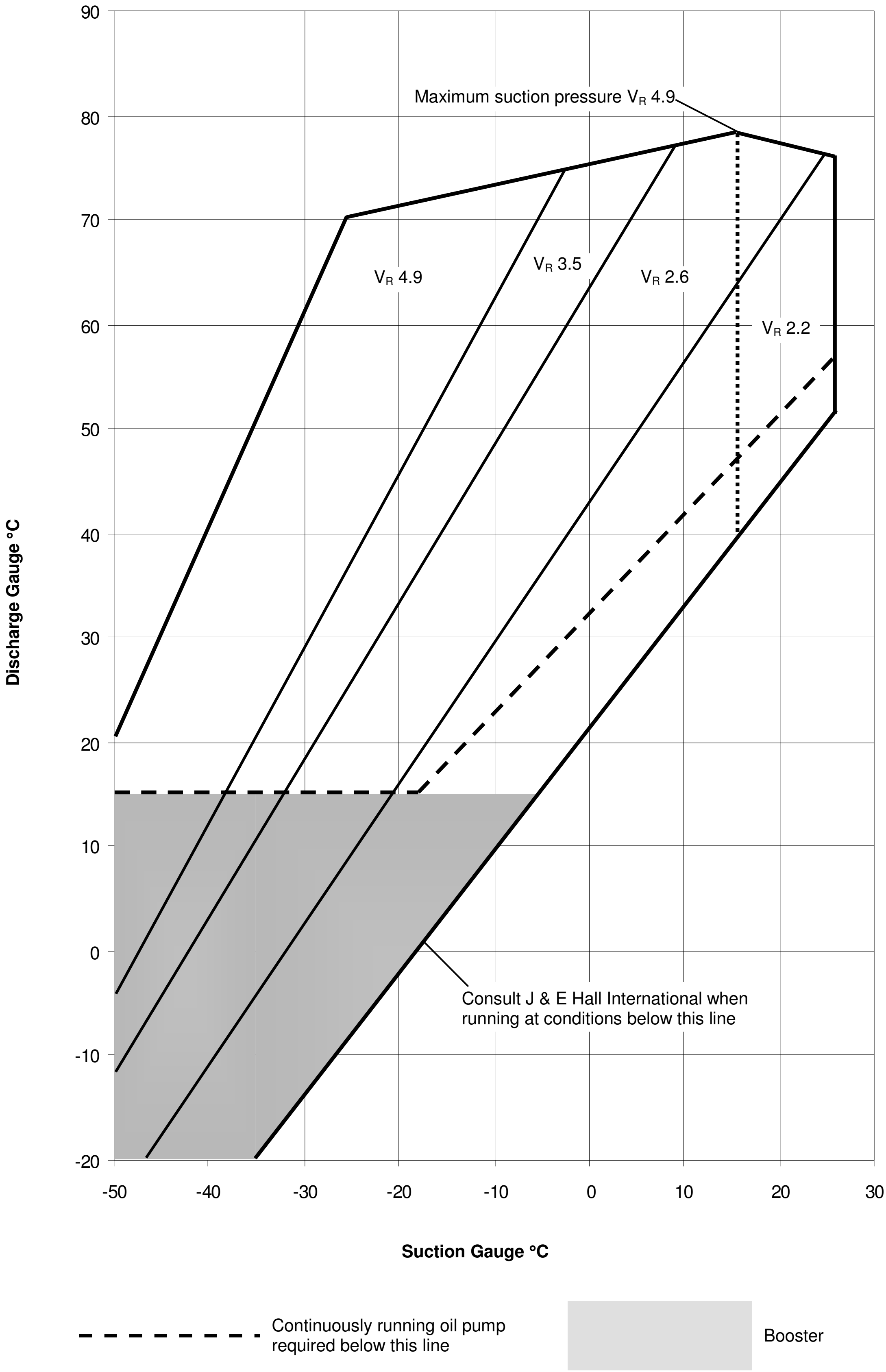
This diagram is approximate, for guidance only. Refer to HallScrew selection software for definitive envelopes.

Limits of Operation R717 (Ammonia)



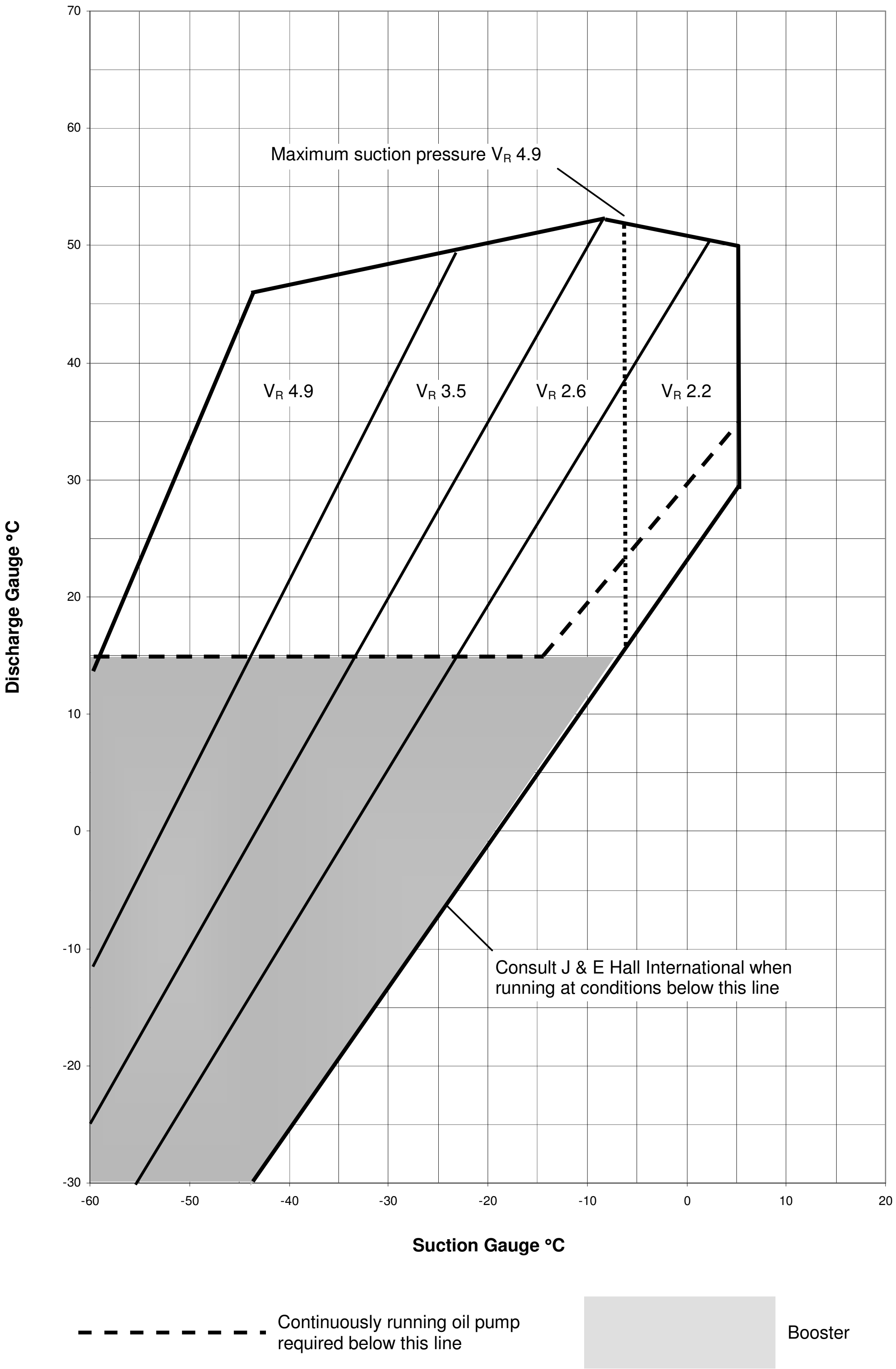
This diagram is approximate, for guidance only. Refer to HallScrew selection software for definitive envelopes.

Limits of Operation R134a



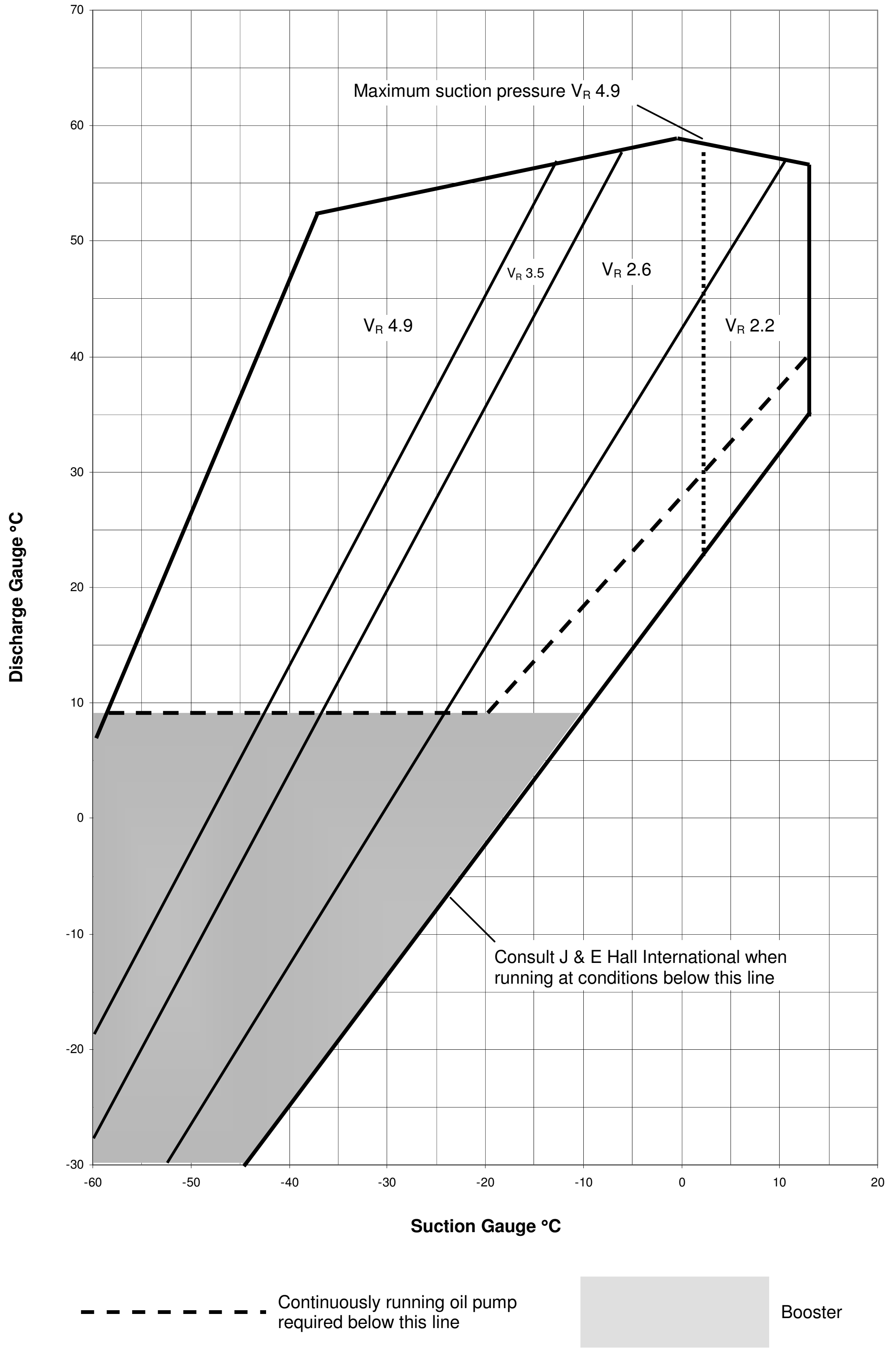
This diagram is approximate, for guidance only. Refer to HallScrew selection software for definitive envelopes.

Limits of Operation R404a and R507A



This diagram is approximate, for guidance only. Refer to HallScrew selection software for definitive envelopes.

Limits of Operation R407c



This diagram is approximate, for guidance only. Refer to HallScrew selection software for definitive envelopes.

Appendix 4 HS 2000 Series Compressor Replacement Parts

HSO 2024						
Item	**Diagram**	**Description**	**Part Number**	**Old Part Number**	**Serial Number 95154-4**-*****	**Serial Number Begins with 'C'**
		Survey Kit				
1	N/A	Survey Kit	N33050009	95812-415	1	1
		Gland Seal				
2	N/A	Gland Seal Kit (standard, for applications using R22 or R717 and mineral oil)	N02020047	95812-402	1	
2	N/A	Gland Seal Kit (silicon carbide, for applications using HFC refrigerant and ester oil)	N02020046	95812-437	1	1
		Star Kit				
3	N/A	Star Kit	N02280018	95822-401	1	1
		Bearings				
4	N/A	Star Bearing Kit	N02050069	95812-404	1	1
5	N/A	Main Bearing Kit	N02050068	95812-407	1	1
		Capacity Control Piston Ring				
6	N/A	Piston Ring (Glyd Ring) and 'O' Ring Kit	N02630014	95812-405	1	1
		Oil Tubes				
7	N/A	Oil Tube Kit (serial number ends <500)	N02210022	95822-455	1	1
7	N/A	Oil Tube Kit (serial number ends >500)	N02210038	95822-445	1	1
		Capacity Control Slides				
8	N/A	Capacity Control Slide Kit 2.2 V_R (serial number ends <500)	N02860038	95822-403	1	
8	N/A	Capacity Control Slide Kit 2.6 V_R (serial number ends <500)	N02860039	95822-404	1	
8	N/A	Capacity Control Slide Kit 3.5 V_R (serial number ends <500)	N02860040	95822-405	1	
8	N/A	Capacity Control Slide Kit 4.9 V_R (serial number ends <500)	N02860041	95822-406	1	
8	N/A	Capacity Control Slide Kit 2.2 V_R (serial number ends >500)	N02860094	95822-423	1	1
8	N/A	Capacity Control Slide Kit 2.6 V_R (serial number ends >500)	N02860095	95822-424	1	1
8	N/A	Capacity Control Slide Kit 3.5 V_R (serial number ends >500)	N02860096	95822-425	1	1
8	N/A	Capacity Control Slide Kit 4.9 V_R (serial number ends >500)	N02860097	95822-426	1	1
		Gasket, 'O' Ring and Lockwasher Set				
9	N/A	Gasket, 'O' Ring and Lockwasher Set	N33010046	95822-402	1	1
		Main Rotor				
10	N/A	Main Rotor and Main Bearing Kit	N02240009	95822-409	1	1
		Tool Kits				
11	N/A	Tool Kit A (for star, slide and piston replacement)	N29960018	95777-104	1	1
12	N/A	Tool Kit B (for bearing and rotor replacement)	N29960019	95777-204	1	

HSO 2028						
Item	**Diagram**	**Description**	**Part Number**	**Old Part Number**	**Serial Number 95154-5**-*** **	**Serial Number Begins with 'C'**
		Survey Kit				
1	N/A	Survey Kit	N33050011	95812-515	1	1
		Gland Seal				
2	N/A	Gland Seal Kit (standard, for applications using R22 or R717 and mineral oil)	N02020051	95812-520	1	
2	N/A	Gland Seal Kit (silicon carbide, for applications using HFC refrigerant and ester oil)	N02020050	95812-538	1	1
		Star Kit				
3	N/A	Star Kit	N02280019	95822-501	1	1
		Bearings				
4	N/A	Star Bearing Kit	N02050074	95812-507	1	1
5	N/A	Main Bearing Kit	N02050072	95812-511	1	1
		Capacity Control Piston Ring				
6	N/A	Piston Ring (Glyd Ring) and 'O' Ring Kit	N02630015	95812-508	1	1
		Oil Tubes				
7	N/A	Oil Tube Kit (serial number ends <500)	N02210023	95822-555	1	1
7	N/A	Oil Tube Kit (serial number ends >500)	N02210039	95822-545	1	1
		Capacity Control Slides				
8	N/A	Capacity Control Slide Kit 2.2 V_R (serial number ends <500)	N02860042	95822-503	1	
8	N/A	Capacity Control Slide Kit 2.6 V_R (serial number ends <500)	N02860043	95822-504	1	
8	N/A	Capacity Control Slide Kit 3.5 V_R (serial number ends <500)	N02860044	95822-505	1	
8	N/A	Capacity Control Slide Kit 4.9 V_R (serial number ends <500)	N02860045	95822-506	1	
8	N/A	Capacity Control Slide Kit 2.2 V_R (serial number ends >500)	N02860098	95822-523	1	1
8	N/A	Capacity Control Slide Kit 2.6 V_R (serial number ends >500)	N02860099	95822-524	1	1
8	N/A	Capacity Control Slide Kit 3.5 V_R (serial number ends >500)	N02860100	95822-525	1	1
8	N/A	Capacity Control Slide Kit 4.9 V_R (serial number ends >500)	N02860101	95822-526	1	1
		Gasket, 'O' Ring and Lockwasher Set				
9	N/A	Gasket, 'O' Ring and Lockwasher Set	N33010047	95822-502	1	1
		Main Rotor				
10	N/A	Main Rotor and Main Bearing Kit	N02240010	95822-509	1	1
		Tool Kits				
11	N/A	Tool Kit A (for star, slide and piston replacement)	N29960021	95777-105	1	1
12	N/A	Tool Kit B (for bearing and rotor replacement)	N29960022	95777-205	1	

HSO 2031						
Item	**Diagram**	**Description**	**Part Number**	**Old Part Number**	**Serial Number 95154-6**-*****	**Serial Number Begins with 'C'**
		Survey Kit				
1	N/A	Survey Kit	N33050013	95812-615	1	1
		Gland Seal				
2	N/A	Gland Seal Kit (standard, for applications using R22 or R717 and mineral oil)	N02020053	95812-620	1	
2	N/A	Gland Seal Kit (silicon carbide, for applications using HFC refrigerant and ester oil)	N02020052	95812-636	1	1
		Star Kit				
3	N/A	Star Kit	N02280020	95822-601	1	1
		Bearings				
4	N/A	Star Bearing Kit	N02050078	95812-604	1	1
5	N/A	Main Bearing Kit	N02050077	95812-607	1	1
		Capacity Control Piston Ring				
6	N/A	Piston Ring (Glyd Ring) and 'O' Ring Kit	N02630016	95812-605	1	1
		Oil Tubes				
7	N/A	Oil Tube Kit (serial number ends <500)	N02210024	95822-655	1	1
7	N/A	Oil Tube Kit (serial number ends >500)	N02210040	95822-645	1	1
		Capacity Control Slides				
8	N/A	Capacity Control Slide Kit 2.2 V_R (serial number ends <500)	N02860046	95822-603	1	
8	N/A	Capacity Control Slide Kit 2.6 V_R (serial number ends <500)	N02860047	95822-604	1	
8	N/A	Capacity Control Slide Kit 3.5 V_R (serial number ends <500)	N02860048	95822-605	1	
8	N/A	Capacity Control Slide Kit 4.9 V_R (serial number ends <500)	N02860049	95822-606	1	
8	N/A	Capacity Control Slide Kit 2.2 V_R (serial number ends >500)	N02860102	95822-623	1	1
8	N/A	Capacity Control Slide Kit 2.6 V_R (serial number ends >500)	N02860103	95822-624	1	1
8	N/A	Capacity Control Slide Kit 3.5 V_R (serial number ends >500)	N02860104	95822-625	1	1
8	N/A	Capacity Control Slide Kit 4.9 V_R (serial number ends >500)	N02860105	95822-626	1	1
		Gasket, 'O' Ring and Lockwasher Set				
9	N/A	Gasket, 'O' Ring and Lockwasher Set	N33010048	95822-602	1	
9	N/A	Gasket, 'O' Ring and Lockwasher Set	N33010054	95812-630		1
		Main Rotor				
10	N/A	Main Rotor and Main Bearing Kit	N02240011	95822-609	1	
10	N/A	Main Rotor and Main Bearing Kit	N02240018	95812-628		1
		Tool Kits				
11	N/A	Tool Kit A (for star, slide and piston replacement)	N29960024	95777-106	1	1
12	N/A	Tool Kit B (for bearing and rotor replacement)	N29960025	95777-206	1	

HSO 2035						
Item	**Diagram**	**Description**	**Part Number**	**Old Part Number**	**Serial Number 95154-7**-*****	**Serial Number Begins with 'C'**
		Survey Kit				
1	N/A	Survey Kit	N33050014	95812-715	1	1
		Gland Seal				
2	N/A	Gland Seal Kit (standard, for applications using R22 or R717 and mineral oil)	N02020055	95812-720	1	
2	N/A	Gland Seal Kit (silicon carbide, for applications using HFC refrigerant and ester oil)	N02020054	95812-736	1	1
		Star Kit				
3	N/A	Star Kit	N02280021	95822-701	1	1
		Bearings				
4	N/A	Star Bearing Kit	N02050080	95812-704	1	1
5	N/A	Main Bearing Kit	N02050079	95812-707	1	1
		Capacity Control Piston Ring				
6	N/A	Piston Ring (Glyd Ring) and 'O' Ring Kit	N02630017	95812-705	1	1
		Oil Tubes				
7	N/A	Oil Tube Kit (serial number ends <500)	N02210025	95822-755	1	1
7	N/A	Oil Tube Kit (serial number ends >500)	N02210041	95822-745	1	1
		Capacity Control Slides				
8	N/A	Capacity Control Slide Kit 2.2 V_R (serial number ends <500)	N02860050	95822-703	1	
8	N/A	Capacity Control Slide Kit 2.6 V_R (serial number ends <500)	N02860051	95822-704	1	
8	N/A	Capacity Control Slide Kit 3.5 V_R (serial number ends <500)	N02860052	95822-705	1	
8	N/A	Capacity Control Slide Kit 4.9 V_R (serial number ends <500)	N02860053	95822-706	1	
8	N/A	Capacity Control Slide Kit 2.2 V_R (serial number ends >500)	N02860106	95822-723	1	1
8	N/A	Capacity Control Slide Kit 2.6 V_R (serial number ends >500)	N02860107	95822-724	1	1
8	N/A	Capacity Control Slide Kit 3.5 V_R (serial number ends >500)	N02860108	95822-725	1	1
8	N/A	Capacity Control Slide Kit 4.9 V_R (serial number ends >500)	N02860109	95822-726	1	1
		Gasket, 'O' Ring and Lockwasher Set				
9	N/A	Gasket, 'O' Ring and Lockwasher Set	N33990003	95822-702	1	
		Main Rotor				
10	N/A	Main Rotor and Main Bearing Kit	N02240012	95822-709	1	
10	N/A	Main Rotor and Main Bearing Kit	N02240019	95812-728		1
		Tool Kits				
11	N/A	Tool Kit A (for star, slide and piston replacement)	N29960026	95777-107	1	1
12	N/A	Tool Kit B (for bearing and rotor replacement)	N29960027	95777-207	1	

Obtain replacement parts from the address below:

J & E Hall International	Telephone: +44 (0) 1332-253400
Hansard Gate,	Fax: +44 (0) 1332-371061
West Meadows,	Email: Halltherm@jehall.co.uk
Derby,	Website: www.jehall.com
DE21 6JN	
England	

The compressor design and construction is subject to change without prior notice.

Appendix 5 Plant Performance Record

It cannot be too strongly emphasised that the regular and accurate logging of plant performance data makes an important contribution to safety, efficiency and reliability, by ensuring that the plant operates within the design conditions. This important point is highlighted in BS EN 378-2 : 2000. If variations from normal are noted without delay, steps can then be taken immediately to discover and, if necessary, rectify the cause.

When consulting J & E Hall International about the operation of the plant, send a copy of the performance record.

Methods of Recording Data

There are a number of different methods of recording and storing this information. A popular method for small plants is the traditional, hand-written log sheet. For large plants a better method would be a computer database, or a plant monitoring system with a data-logging facility.

When designing a log sheet for the plant, either on paper or as an electronic form held in a computer database, there are certain pressures, temperatures and flow rates which are common to nearly every plant; these are shown on the typical log sheet. Other variables, equally important, are peculiar to different plants; these must be observed and logged to obtain a complete picture of performance.

Log Book

Completed log sheets should be collated to form a log book. Basic information about the plant should be recorded at the front of the log book.

- Title.
- Plant location.
- Date plant was commissioned.
- Compressor model and serial number(s).
- Refrigerant and quantity of charge.
- Type and method of refrigerant regulation.
- Condenser type and cooling medium.
- Evaporator type and cooled medium. For aqueous solutions, for example alcohols, brines or glycols, record the % concentration and specific gravity.

It is also recommended to record the following information:

- Details of all maintenance and repair work.
- The quantity of refrigerant charged or removed from the system.
- The quantity and grade of oil added or drained from the system.
- Changes and replacement of components.
- The results of all tests.
- Trip events and their cause.

DATE										
TIME										
LOG TAKEN BY										
COMPRESSOR										
Hours Run........										
% Capacity........										
Net Oil Pressure at Compressor........										
Oil Temperature (°C)........										
COMPRESSOR MOTOR										
Speed (rpm)........										
Volt										
Amp										
[1]**GAUGE TEMPERATURES**										
Evaporator (°C)										
Suction (°C)										
Intermediate (°C)........										
Discharge (°C)										
Economiser (°C)........										
REFRIGERANT TEMPERATURES										
At Evaporator (°C)........										
LP Suction (°C)										
LP Discharge (°C)										
HP Discharge (°C)										
Economiser (°C)........										
[2]**OIL COOLER COOLING MEDIUM**										
Inlet Temperature (°C)										
Outlet Temperature (°C)........										
Rate of Flow (m^3/h)										
CONDENSER COOLING MEDIUM										
Inlet Temperature (°C)										
Outlet Temperature (°C)........										
Rate of Flow (m^3/h)										
[3]Ambient Dry Bulb Temperature (°C)........										
[3]Ambient Wet Bulb Temperature (°C)........										
EVAPORATOR COOLED MEDIUM										
Inlet Temperature (°C)										
Outlet Temperature (°C)........										
Rate of Flow (m^3/h)										
LIQUID REFRIGERANT TEMPERATURES										
At the Condenser Outlet (°C)										
Before the Regulator (°C)........										

[1]It is also desirable to give the gauge temperature readings approximately 15 minutes after the plant has stopped.
[2]Required for refrigerant or water cooled oil cooling.
[3]Required for air cooled or force draught evaporative condensers.

Appendix 6 Pepperl & Fuchs Signal Conditioning Module KFU8-USC-1.D Set-up

Basic Set up for 4 mA and 20 mA Output Values at Minimum and Maximum Slide Valve Positions

Refer to Table 8.

The KFU8-USC-1.D module can be used simply to calibrate the output from the MSI LVDT to provide 4 mA and 20 mA signals, at the compressor minimum and maximum slide valve positions respectively, by following the instructions in Table 8. Setting the 'Start Value' (at minimum load) and setting the 'End Value' (at maximum load) are independent processes. The End Value setting can be made at any time after the Start Value setting. The values can be reset at any time. If necessary, the unit can be reset to the factory settings by following the instructions in the Pepperl & Fuchs manual included with the unit.

Setting the Display to Read 0 at Minimum Load and 100 at Maximum Load

Refer to Table 9.

This procedure is optional and not necessary for the basic calibration of the signal from the MSI LVDT, however it is useful for setting a slide valve position for the relay switch. It also provides a visual display of the slide position as if it were a percentage value.

> **NOTE: although '%' is a unit option in the module, this cannot be used as the units for this application because it has a pre-programmed function which does not allow the required 'Factor' to be set up (also 'mA' cannot be used as a unit because this is the same as the input units). It is therefore recommended that 'l' is used for the units; this allows the 'Zero' and 'Factor' to be set to give the 0 to 100 numerical values required even though the actual unit is not meaningful.**

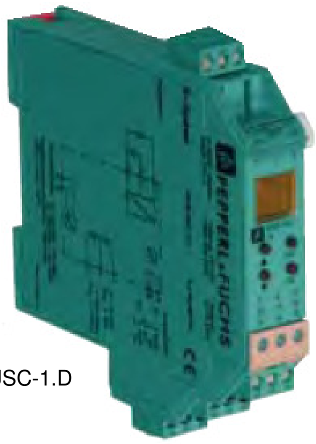
Unless the 'units' are reconfigured, the value displayed on the module is always the actual **input value** in mA from the LVDT. This is not particularly meaningful for the user.

To set the relay switch trip point, the value must be in the units displayed, so if not reconfigured, this would need to be calculated from the input mA for a given slide valve position. It is therefore easier to set the trip point if the display reads 0 at minimum load and 100 at maximum load, then the switch point trip value can be set as if it were a percentage slide valve position.

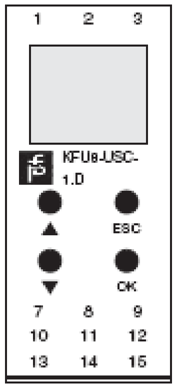
Setting the Relay Switch Value

Refer to Table 10.

Once the display units have been reconfigured to 'l' and the display values at minimum and maximum load slide positions are 0 and 100 respectively, the switch (Trip) point can be set as a value as if it were a percentage. The 'Hysteresis' value can also be set as equivalent to a percentage. Depending on how it is required for the switch hysteresis to operate with rising and falling values, the module can be configured accordingly; refer to the note at the bottom of Table 10. This is also demonstrated fully in the Pepperl & Fuchs manual included with the unit).



KFU8-USC-1.D



Display

Slide Valve Position	Action	Input		Output	
		Display	Comment	Value	Comment
Minimum load	Record value displayed on unit	6.235 mA	For example	6.235 mA	Start
	Press buttons on Display:				
	ESC + OK (together)	Unit			
	▼	Input			
	▼	Output			
	OK	Relay			
	▼	Analogue Out			
	OK	Characteristic			
	OK	0 to 20 mA	'Flashing'		
	▼	4 to 20 mA NE4	'Flashing'	6.235 mA	
	OK	4 to 20 mA NE4	Set (saved)	9.0 mA	Temporary value
	ESC	Characteristic			
	▼	Start Value			
	OK	Numeric			
	▼	Teach In			
	OK	6.235 mA	'Flashing'	9.0 mA	
	OK	6.235 mA	Start value saved	4 mA	Minimum load set
	ESC	Teach In			
	ESC	Start Value			
	ESC	Analogue Out			
	ESC	Output			
Minimum load	ESC	6.235 mA	Default screen	4 mA	

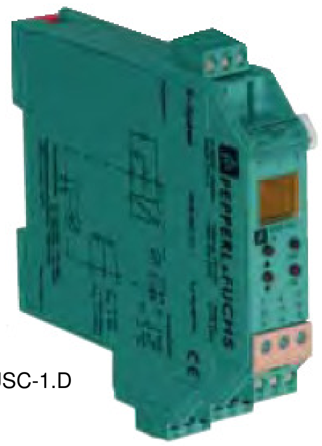
Table 8 Basic Set up for 4 mA and 20 mA Output Values at Minimum and Maximum Slide Valve Positions

Slide Valve Position	Action	Input		Output	
		Display	Comment	Value	Comment
Maximum load	Record value displayed on unit	15.76 mA	For example	15.1mA	Temporary value
↓	Press buttons on Display			↓	
	ESC + OK (together)	Unit			
	▼	Input			
	▼	Output			
	OK	Relay			
	▼	Analogue Out			
	OK	Characteristic			
	▼	Start Value			
	▼	End Value			
	OK	Numeric			
	▼	Teach In			
	OK	15.76 mA	'Flashing'	15.1 mA	
	OK	15.76 mA	End value saved	20 mA	Maximum load set
	ESC	Teach In		↓	
	ESC	End Value			
	ESC	Analogue Out			
	ESC	Output			
Maximum load	ESC	15.76 mA	Default screen	20 mA	Finish
Minimum load		6.235 mA		4 mA	

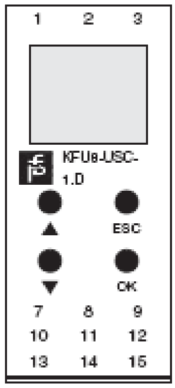
NOTE: Setting the 'Start Value' (at minimum load) and setting the 'End Value' (at maximum load) are independent processes. The End Value setting can be made at any time after the Start value setting.

Table 8 (continued) Basic Set up for 4 mA and 20 mA Output Values at Minimum and Maximum Slide Valve Positions

This procedure is optional but recommended for easy set up of the relay switch point (if used); refer to Table 10



KFU8-USC-1.D



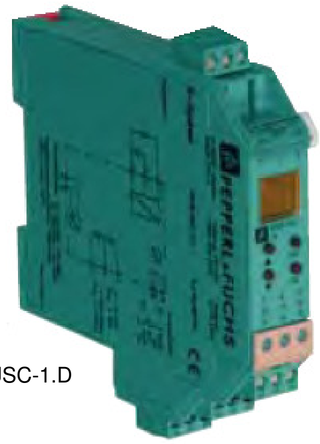
Display

Slide Valve Position	Action	Input		Output Value
		Display	Comment	
[1]Min load		6.235 mA	For example	4 mA
	Press the following buttons			
	ESC+OK (together)	Unit		
	OK	mA	'Flashing'	
	▼	[2]%	'Flashing'	
	▼	[2]l	'Flashing'	
	OK	[2]l	Unit set	
	ESC	Unit		
	▼	Input		
	OK	Type		
	▼	Zero		
	OK	4.000	'Flashing'	
	▲ ▼	6.23 mA	Set value = min load input value	
	OK	6.23 mA	Zero set	
	ESC	Zero		
	▼	Factor		
	OK	1.000	'Flashing'	
	▲ ▼	10.49	Set value = 100/(15.765 - 6.235)	
	OK	10.49	Multiplying factor set	
	ESC	Factor		
	ESC	Input		
Min load	ESC	0.000	% slide valve setting	4 mA
Max load		100.0	% slide valve setting	20 mA

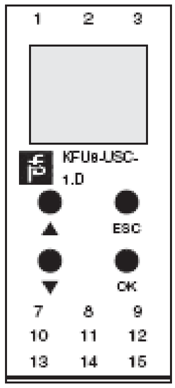
[1]Operation can be done with the slide valve in any position.
[2]The unit of % cannot be chosen for this application because of the special functionality given to it inbuilt in the unit (for example, if % is chosen as the unit then the required Factor cannot be set). Therefore it is suggested that 'l' is chosen as the unit for simplicity although it must be recognised that for this application the unit does not any real meaning, i.e. the value is dimensionless or can be interpreted as a percentage value.

Table 9 Setting the Display to Read 0 at Minimum Load and 100 at Maximum Load

Set the display to read 0 at minimum load and 100 at maximum load before setting the relay switch value



KFU8-USC-1.D



Display

Slide Valve Position	Action	Input		Output Value
		Display	Comment	
[1]Min load		0.000	For example	4 mA
	Press the following buttons			
	ESC + OK (together)	Unit		
	▼	Input		
	▼	Output		
	OK	Relay		
	OK	[2]MIN/MAX	Default set to MIN	
	▼	Trip		
	OK	102.4	For example 'Flashing'	
	▲ ▼	70.00	Set value (for example) 'Flashing'	
	OK	70.00	Trip value set	
	ESC	Trip		
	▼	Hysteresis		
	OK	20.98	For example 'Flashing'	
	▲ ▼	2.000	Set value (for example) 'Flashing'	
	OK	2.000	Hysteresis value set	
	ESC	Hysteresis		
	ESC	Relay		
	ESC	Output		
Min load	ESC	0.000		4 mA

[1]Operation can be done with the slide valve in any position.
[2]MIN setting will make/break switch at Trip value when value is falling. When value is rising, the switch will break/make at the Trip value + Hysteresis value. MAX setting will make/break switch at Trip value when value is rising. When value is falling, the switch will break/make at the Trip value – Hysteresis value; refer to pages 18 and 19 of the Pepperl & Fuchs manual included with the unit.

Table 10 Setting the Relay Switch Value

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