

MODERNIZING A PROVEN RECIPROCATING COMPRESSOR LINE

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ABSTRACT

Dresser-Rand recognized the need to modernize their proven heavy process reciprocating compressor line. The company considered key factors such as manufacturing economics, reliability and ease of maintenance during the design stage. The result was the design of four cylinder lineups. Improvements were also made in the frame and running gear, the crosshead, access opening in distance pieces and hydraulic bolt tensioning. Dresser-Rand now has a series of modern frames available up to 270,000 lbs rod load.

INTRODUCTION

As Dresser-Rand approaches the new millennium it recognized that a modernized heavy process compressor lineup is needed. The compressor lineup was designed to meet best current design practices, be easy to maintain, as well as be reliable and economical to manufacture.

The modern cylinder lineup is based on the latest cylinder design technology. Many patterns were eliminated because they did not meet the requirements, and many were simply worn out. Over \$1 million has been invested in cylinder patterns. There are four lineups of heavy process cylinder designs, for various rod load ratings over 30,000 lbs up to 270,000 lbs. All designs have been analyzed using FEA. Each cylinder has been strain gauge tested to prove the FEA model and selected cylinders have been burst tested. All cylinders within a rod load class have a common distance piece bolt circle so that only one distance piece design is required. New distance pieces have been designed. These have external bolting that can easily be tensioned. Large access openings are provided to simplify packing maintenance. The distance piece is very rigid to prevent cylinder alignment problems. Extensive cooperation has been made with the foundry and with manufacturing to ensure that sound castings can be economically produced.

Improvements have been made in the frame and running gear. The crosshead on larger frame sizes has been redesigned to eliminate the threaded connection between the piston rod and crosshead. A flange design crosshead with hydraulically tensioned studs is used on 4" piston rods and larger. The crosshead pin on all frame sizes is full floating for ease of maintenance. The crosshead material is ASTM A536 Grade 60/40/18 nodular iron. This material has proven to be the best for crossheads. It is readily castable, has good ductility and has excellent fatigue properties. The connecting rod pin bushing is grooved and the pin is non-rotating in the crosshead. This design provides good lubrication of the bushing, and is quite tolerant of poor rod load reversal (for example due to a valve failure.) Hydraulic tensioning is standard on all frame and cylinder bolting 1.375" and larger. With these design improvements Dresser-Rand has a series of modern frames available up to 270,000 lbs rod load. The machines have been designed to be reliable, easy to maintain and to meet the customer requirements.

CYLINDERS

Dresser-Rand has redesigned their lineup of process compressor cylinders. This was done for the following reasons:

- Due to old design, frequently modified and worn out wooden patterns, there was a significant casting quality problem with high scrap rates on many patterns.
- Internal cylinder clearances were high resulting in low volumetric efficiency.
- High costs.

- Designs that were unfriendly to the customer's maintenance crews. There was some internal bolting that was difficult to reach and could only be tightened with 'slugging' wrenches.

A lineup of cylinders was designed to meet various compressor rod loads (Maximum Allowable Continuous Combined Rod Load) up to 270,000 lbs. Some of the patterns are used over more than one frame size. In designing the cylinders considerable effort was made in researching the requirements of the customer, our field service engineers, assembly, machining, and of course the foundry. As these are Process cylinders they were all designed with full water jackets around the cylinder bore. This type of water jacket, which is quite expensive, is required to control the cylinder temperature to prevent gas condensation in the inlet passage. Efficient water jackets keep the cylinder bore wall cool for maximum ring life, especially important for non lube applications and also dissipate heat during unloaded operation.

The foundry was consulted during the design phase of every cylinder pattern. This results in castings that are ideally suited to modern casting technology. There was a large reduction in the number of foundry molding cores (for example the existing A38 pattern had 29 cores, the replacement CL5-40 pattern has only four). There are several results, including a reduction in labor, fewer cores meaning less chance of core shift, fewer fins that need to be ground off, better dimensional control to allow automatic machining of cylinders, and better casting quality. All pattern variations were designed into the basic pattern, including bore and valve sizes. Only one material will be used (ASTM A395 Class 60/40/18 Nodular Iron). This means that the foundry will not be making pattern alterations, which minimizes wear and tear of the patterns and reduces the chance for foundry error. The designs are such that chaplets are not required. (Chaplets are often used to support internal cores and can cause leaks on test. Their use is discouraged by API 618).

Design for Maintenance All cylinders within the same rod load class will use one API type C or type B distance piece. The redesigned distance piece has external bolting that allows for easy and accurate tightening of the bolts. Bolts 1.375" and larger are a size that cannot easily be tightened by hand. They are designed to be tightened either by hydraulic tensioning, hydraulic torquing or, if preferred, by Supernuts. All distance pieces are heavily ribbed for rigidity to minimize rod runout and cylinder vibration. Large access openings are provided for ease of packing maintenance; a fully assembled packing can be installed through the access openings. Figures 1, 2 and 3 show a typical type C distance piece and how the same distance piece fits on a small cylinder, (head inside the distance piece), medium cylinder (sandwich head) and large cylinder (distance piece bolts to the head and the head bolts to the cylinder).

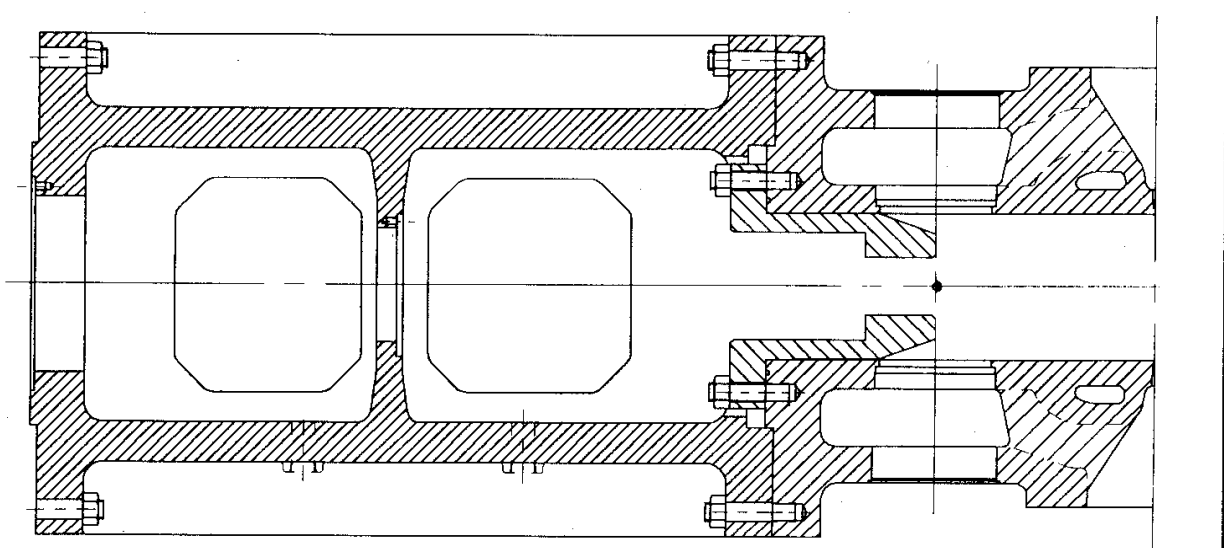


Figure 1. Distance Piece with Small Cylinder.

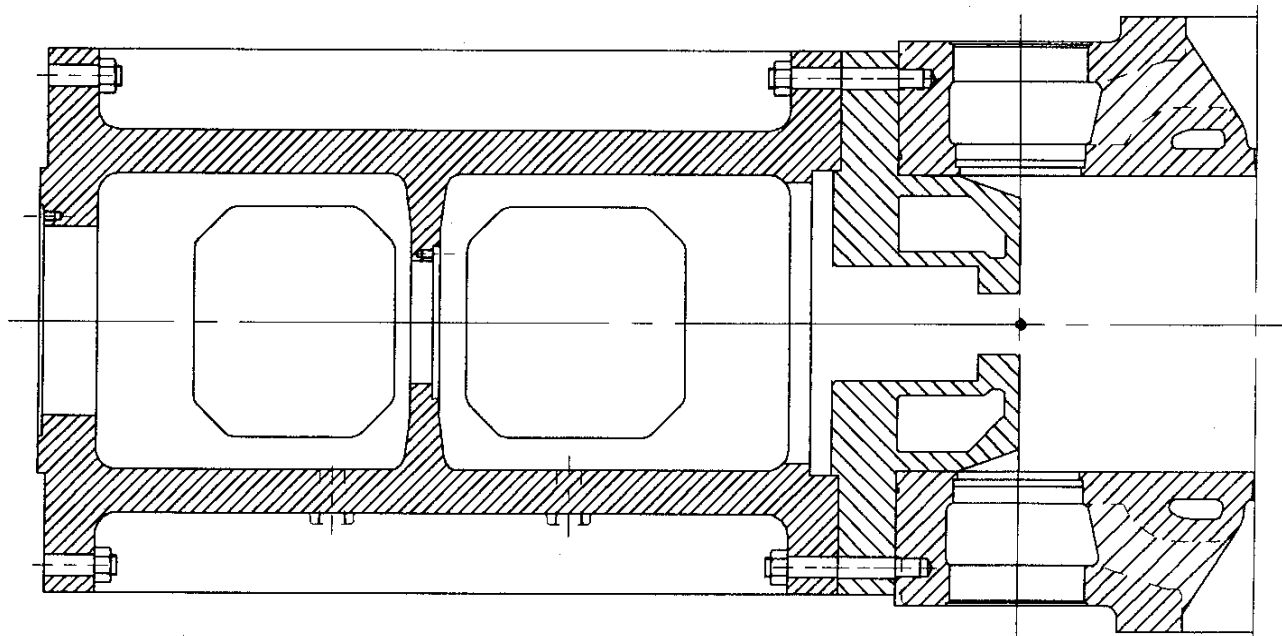


Figure 2. Distance Piece with Medium Cylinder.

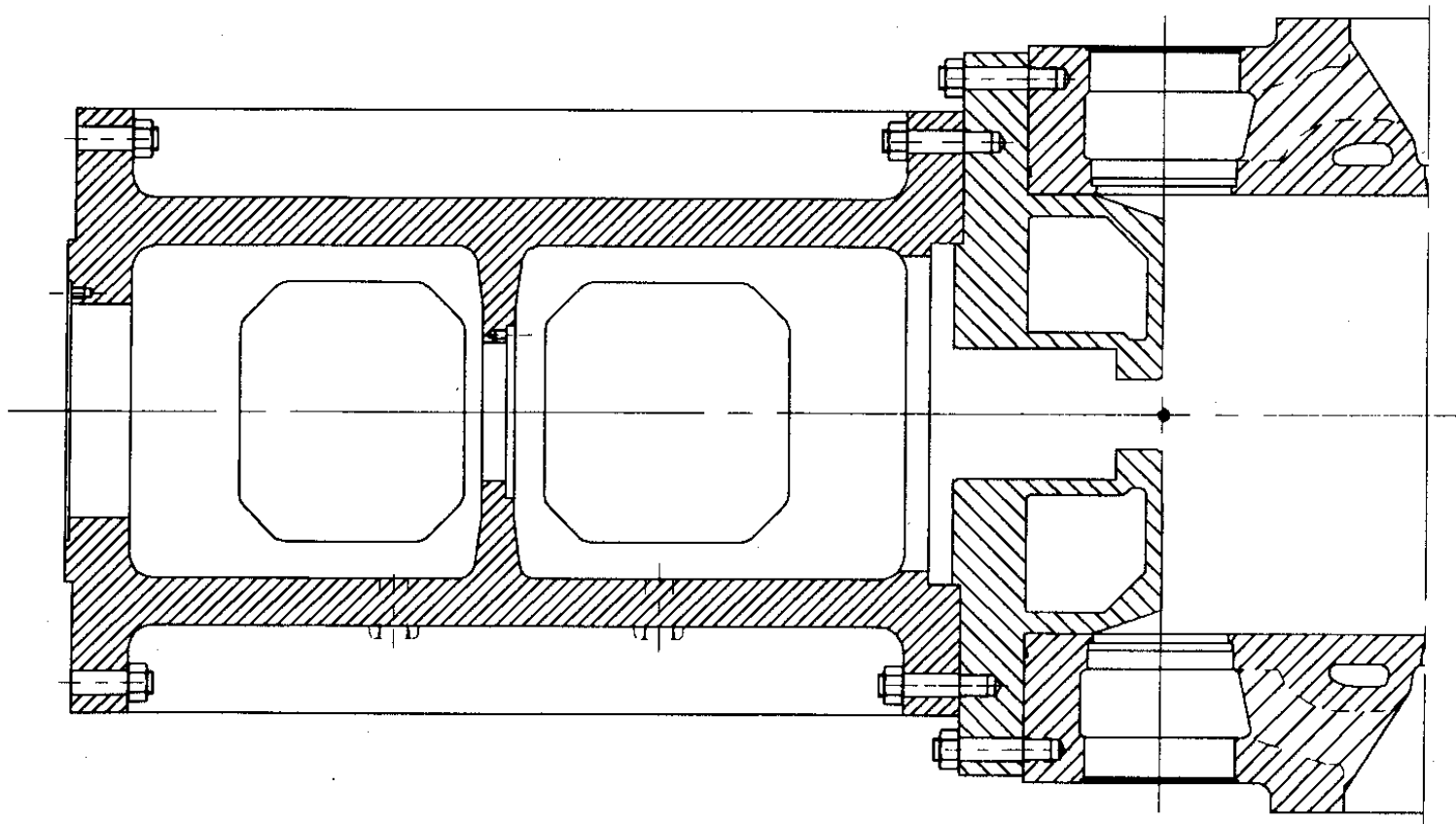


Figure 3. Distance Piece with Large Cylinder.

DOING MORE WITH LESS

Table 1 shows the effect of this program on the number of basic patterns required. This table shows that even though fewer basic patterns are required, more bore sizes are available. Also there is a huge reduction in the number of pattern variations required. This reduction in patterns and pattern variations means savings as well as more reliable castings and shipments for Dresser-Rand and our customers.

	1992 Cyl Line up	1996 Cyl Line up
No Of Different Cylinder Bores	66	69
No Of Different Basic Patterns	31	24
No of Cyl Materials Offered	2	1
No of Valve Sizes Offered	1	2
Total No of Pattern Variations Including Changes in Cylinder Material and Valve Sizes	273	56
No of Distances Piece Variations	40-60	8

Table 1 - Cylinder Lineup. More With Less

Achieving More with Less

- Reduced Wear and tear on Patterns.
- Reduced Pattern Set up Charges
- Fewer Machining Errors
- Faster Assembly Times
- Fewer Different Parts
- Reduced Inventory
- More Reliable Castings.

DESIGN VERIFICATION

Cylinders are designed using normal calculations for hoop stresses and end wall stresses. An FEA was made of the cylinders to check stresses and strengthen any problem areas. All first off cylinders from a new pattern were strain gauged to check the actual stresses and verify the FEA model for each casting. This does not damage the cylinder so it is performed on production cylinders. The cylinder is tested up to hydro test pressure (1.5 times Maximum Allowable Design Pressure, MADP). On two selected castings, a sample casting was purchased and burst tested to verify the design model. The acceptance criteria was a burst pressure equal or

greater than four times MADP. The two castings burst test were the CL3-9" and the CL5-34". Both tests were successful. The cylinders easily passed the four times design requirement. The actual failure mode was achieved by yielding of the material resulting in leaking at the test gasket joints. Dresser-Rand has verified that the material properties in the critical section of the cylinder meet the minimum design requirements. This was done by utilizing 'in mold' test bars on all sample castings. Also by machining tensile test bars and charpy test bars from the critical sections on the two burst test castings.

FRAME LINE UP

Dresser-Rand has modernized their line up of process frames There are now four standard large frames available with rod load ratings of up to 270,000 lbs Maximum Allowable Continuous Combined Rod Load (MACCRL). All frames are based on proven designs. They all use the open top frame tie rod construction. The HHE-VB has a 3" piston rod and uses a threaded piston rod to crosshead connection design with full floating pin and the threaded piston rod locked by a Supernut. The nodular iron HHE-VB crosshead is the same crosshead as is used on the High Speed Separable HOS. It has proven itself in the demanding high speed separable market.

CROSSHEAD DESIGN

The machines with 4" diameter and larger piston rods use a flanged crosshead design. See Figure 4. The crosshead has a round body with cylindrical shoes which are bolted to the crosshead with four cap screws. The shoes are shim-adjustable for adjusting the crosshead-to-guide clearance. The crosshead pin is cylindrical and full floating for easy assembly.

The pin is retained by caps at each end. There is an anti-rotation pin to ensure that it is the pin to connecting rod bushing that acts as the bearing. The conrod bushing is bronze and has helical grooving to provide for lubrication under conditions of zero rod reversal (for example in case of a valve failure).

LUBRICATION

Lubrication is accomplished by a 'gun drilled' oil passage through the connecting rod to the pin to lubricate the pin bushing and the pin-to-crosshead fit. Lubrication of the shoe-to-guide is by separate lube feed from the main oil header to the guide. and by internal drilling in the guide to the shoe running surface.

Piston Rod to Crosshead Joint The piston rod is necked down at the flange and the nut is hydraulically tensioned on the crosshead side to preload the joint. The flange is bolted to the crosshead using six hydraulically tensioned studs. There is an adjusting ring on the nose of the crosshead to allow the piston rod to be adjusted both vertically and horizontally to adjust the piston rod runout. A spacer is provided to adjust piston end clearance.

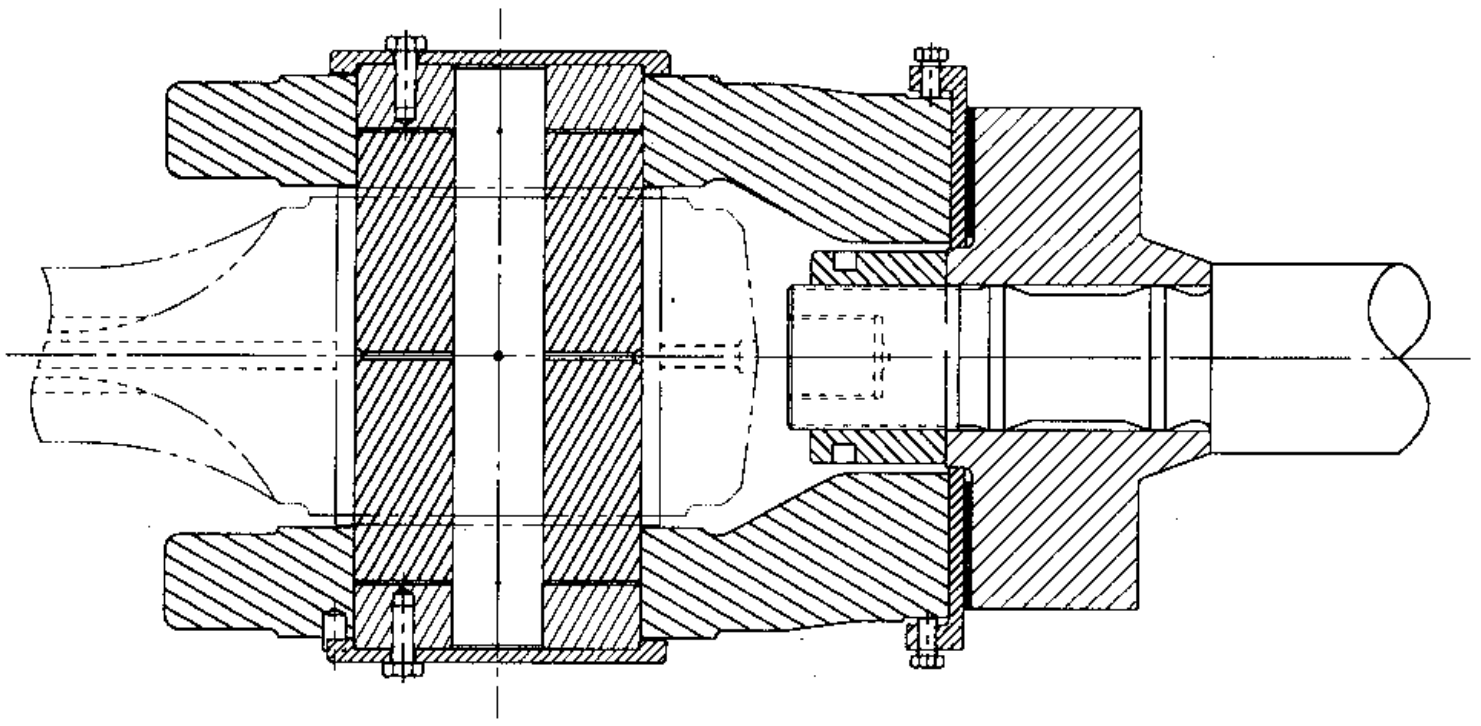


Figure 4. Flanged Crosshead. Plan View.

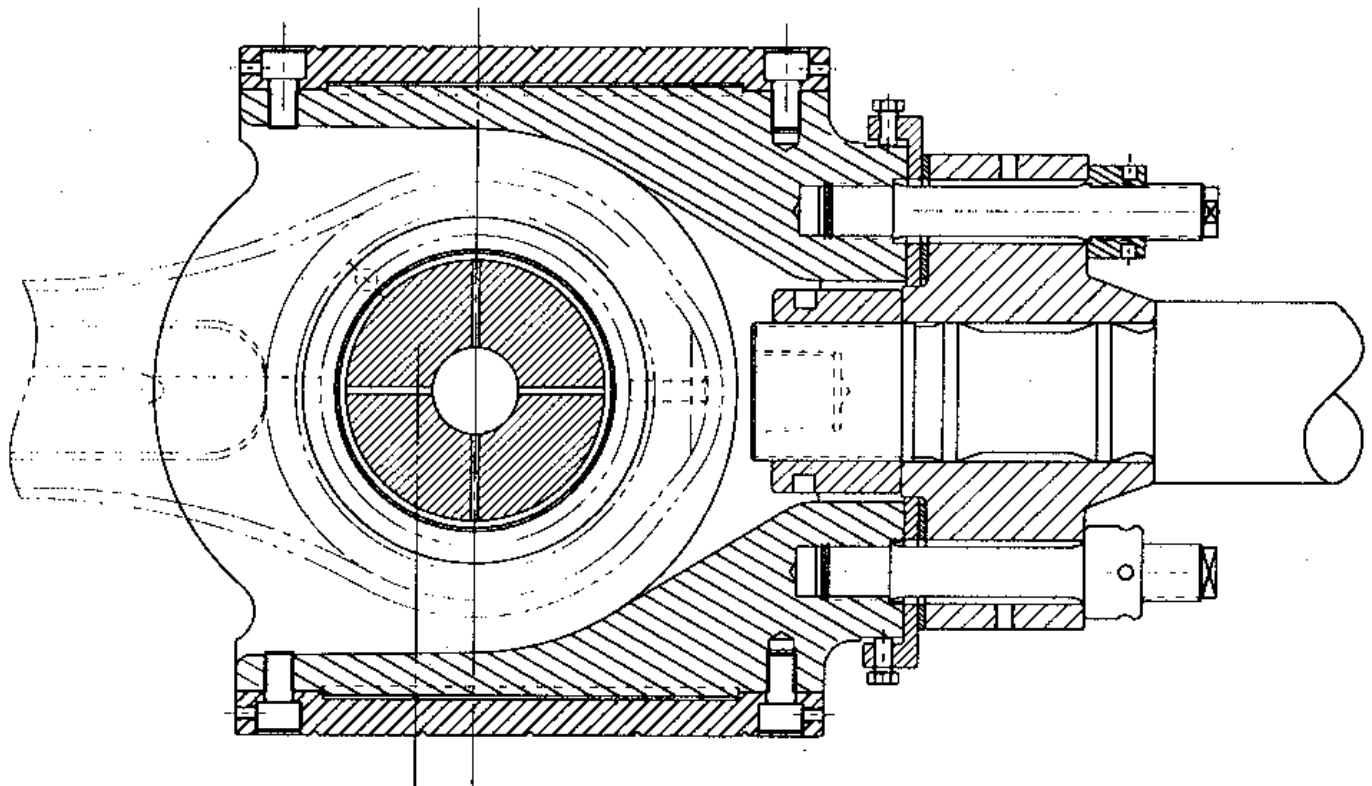


Figure 5. Flanged Crosshead. Front View

Materials The Crosshead body is made of ASTM A536 60-40-18 nodular Iron. This is the best material for a crosshead because it is readily castable, so sound quality castings can be produced without welding repairs as

are normally required on cast steel. This grade of Nodular Iron has excellent fatigue strength for reliable operation. The carbon nodules tend to act as natural crack stoppers to prevent crack initiation and growth. This material has good ductility.

Crosshead Pin - Alloy steel, surface hardened.

Crosshead Shoe - Cast Iron with babbit face.

Connrod Bushing - Bronze.

Flange - Alloy steel.

Studs - ASTM A 193 grade B7

Crankpin and Main Journal Bearings - Aluminum with micro babbit overlay.

DESIGN VERIFICATION

The design of the crosshead has its origins in designs which are well proven within the Dresser-Rand family of compressors. The material, nodular iron is well proven in the demanding HOS separable market. In addition it has been the standard material used for all Worthington BDCs, with many units operating up to and exceeding 200,000 lbs rod load. The floating pin design is similar to the HHE-VB and VE plus the BDC designs. The conn rod bushing design was borrowed from many HHE and BDC designs. The round shoe and flange design came from Dresser-Rand, Germany. A full scale model of the flanged joint was made and strain gauge tested to check actual operating stresses at the design 270,000 lbs rod load in both tension and compression. A scale model was made of the joint and fatigue tested on Dresser-Rand's in house reciprocating fatigue tester.

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