A Design Study in Steel Castings

Hinge/Bearing Assembly for a Rough Terrain Log Forwarder

Design Study Outline

- ***Introduction***
- ***Design for Performance***
  - **Weight Savings and Durability**
  - **Articulation and Function**
- ***Design for Castability/Manufacturability***
  - **Core Design**
  - **Reducing Hot Spots**
  - **Gates and Runners**
  - **Risers**
- ***Finished Design and Casting***
- ***Summary***

Start the Design Study

Acknowledgement --
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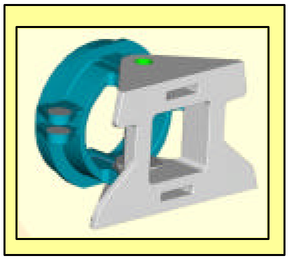
Hinge/Bearing Assembly for a Rough Terrain Log Forwarder



The Application -- This component is an articulating hinge-bearing assembly which acts as the primary structural joint on a 20-ton Log Forwarder made by a major specialty vehicle builder.

- The log forwarder is an articulated two-unit, all-wheel-drive, rough-terrain vehicle used to pick up and haul cut logs from the cutting site to the forest road pick-up point. The front operator unit contains the engine, the operator cab and a hydraulic boom. The rear cargo unit is used to carry the 20 tons of cut logs.

The hinge-bearing assembly consists of two plates and serves as the structural linkage between the front and rear units, providing articulation as well as rotation.

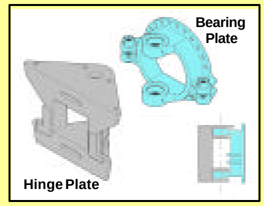
- The drive shaft and the hydraulic lines pass through the assembly.
- The range of swing motion between the front and rear units is a critical factor in providing stability and mobility for the rough-terrain vehicle.

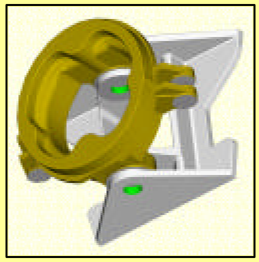
Hinge/Bearing Assembly Description

<u>Component Description</u> -- The hinge-bearing assembly consists of two components

- the hinge plate - 564# cast weight
- the bearing plate - 450# cast weight

- These two components (produced with 1040 steel) are machined for pin bores, bearing and hinge surfaces, grease fittings, and mounting holes.
- The major performance concerns for the assembly are long-term structural durability and unrestricted articulation. The engineering design requires the elimination of stress concentrations and the precise definition of component geometry to provide the required degree of articulation between the two components.
- The finished components are coated with epoxy for appearance and corrosion protection.

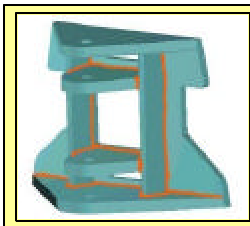


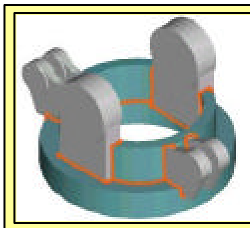


Steel Castings to Improve Performance, Reduce Weight, and Cut Costs

<u>The Challenges</u> -- Originally designed as a welded assemblies, the hinge and bearing plates -

- ✓ Consisted of 40 welded pieces for the bearing plate and 25 welded pieces for the hinge plate. (*Representative weld lines are shown in orange)*
- ✓ Had multiple segments and extensive welding lines and sharp corners which acted as stress concentrators and reduced performance and durability
- ✓ Were not optimized for weight savings.
- ✓ Had significant variation in tolerances and alignment due to fixturing and welding variability.
- ✓ Required full face machining on plate faces.

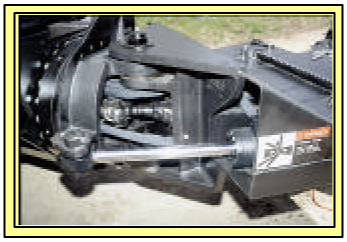




Steel Castings to Improve Performance, Reduce Weight, and Cut Costs

Benefits of Using a Steel Casting --

- The total assembly weight could be reduced by 15% (compared to the original weldment) by using steel castings. This weight reduction was achieved by reducing mass in unstressed sections
- Conversion to a casting improved the strength of the components with more robust cross-sections in stressed areas and generous radii on the contours to reduce stress concentrations.



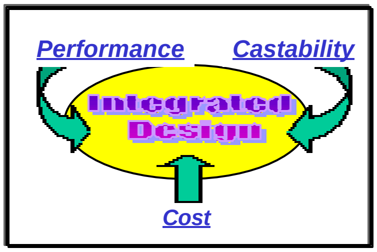
- Production costs were reduced with castings by --
  - Saving final assembly time by eliminating the variability in tolerances and alignment that occurred during fixturing, assembly and welding of a multi-piece weldments.
  - Limiting machining to carefully defined pad areas with targeted machining stock.

These benefits were achieved by a concurrent engineering effort by Grede foundry engineers and vehicle design engineers.

The Casting Design Issues

The Casting Design -- Both castings are produced in sand molds. The casting design engineers at the Grede Foundries Inc.-Milwaukee Steel Division had three imperatives for an integrated casting design:

- ***Design for Performance***
- ***Design for Castability/Manufacturability***
- ***Design for Cost***

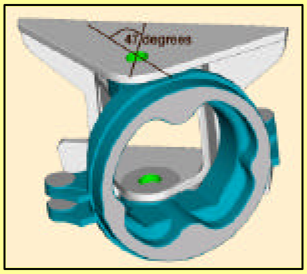


Critical Casting Design Issues --The requirements for performance, manufacturability/ castability, and cost are closely interconnected.
Four casting design issues played a major role in meeting the three design imperatives:

- ✓ Review the ***component design*** to meet performance requirements, save weight and reduce stresses.
- ✓ Consider the ***use of cores*** for producing critical features.
- ✓ Design the component to ensure sound castings by ***reducing hot spots***.
- ✓ Design the ***mold rigging*** (gates and risers) for castings with high reproducibility.

Component Analysis for Performance

A key performance requirement in the hinge/bearing assembly is that the two assembled plates provide the required degree of articulation. Interference between the two plates across the required range of motion has to be checked against the design swing angle.

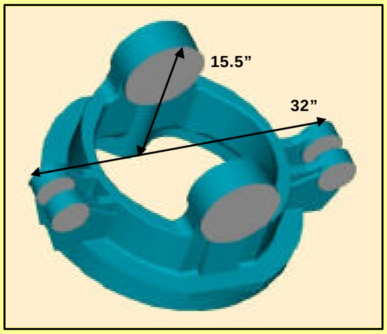


- The major redesign of the two plates made it imperative that the articulation range between the two components -- “the swing”-- be checked against the design target.
- This was done through the engineering software Pro-E, which showed that the angular swing in the redesign was 47^{o} left and right, meeting and exceeding the design target of 45^{o}
- *(The Pro-E graphic figure to the left shows the swing angle)*

Weight Savings

Casting technology provides near-net shape fabricability, which can be used to save weight

- In reengineering the two plates in the hinge/ bearing assembly as castings, vehicle system engineers and the Grede engineers had the design freedom to --
  - build up sections where high stresses were expected
  - reduce metal cross-sections in unstressed regions.
- With the design flexibility of castings, 15% weight savings were achieved compared to the original welded fabrication.



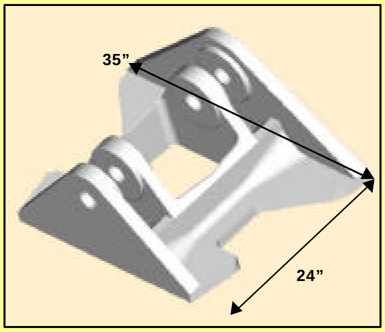
Bearing Plate

Performance Improvement

Casting technology provides near-net shape fabricability, which can be used to improve performance

- Vehicle system engineers and Grede engineers improved the durability in the castings by avoiding stress concentrations, compared to the original welded assembly.

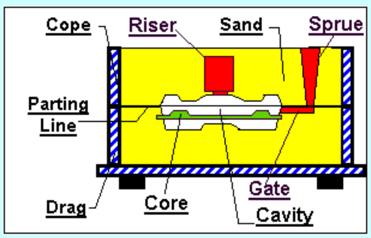
- The improvement was achieved through the elimination of welded joints and the generous use of fillets and radii to reduce stress concentrations at corners and joints.



Hinge Plate

Design for Castability

- Casting engineers produce castings of almost any design and complexity, achieve high quality, and meet performance and cost targets by insuring that "castability" is considered in the basic design.
- Designing for castability insures that sound castings are consistently produced and production costs are minimized.
- The foundry engineer plans how the casting will be produced in the mold considering --
  - The positioning the piece in the mold and location of the parting line.
  - The location of sprues, runners and gates for metal flow into the mold.
  - The use of cores for internal features.
  - The location and size of risers to provide metal for solidification.

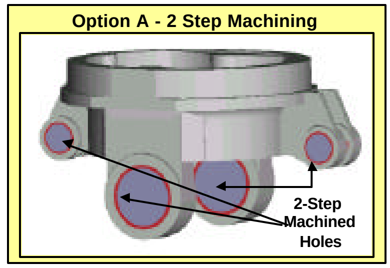


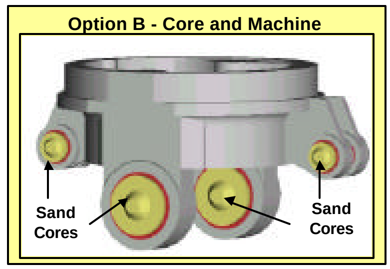
- A review of the hinge and bearing components identified four castability design issues --
  - ***Coring versus Machining***
  - ***Reducing Hot Spots***
  - ***Gates and Runners***
  - ***Riser Size and Positioning***

Coring versus Machining

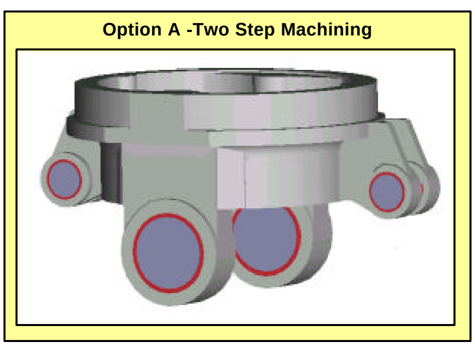
- **The bearing plate requires six holes in the six tabs used for mounting the hinge pins.**
- **The casting engineer has two options in producing these holes.**
  - ***Option A*** -- Produce the six holes in a 2-step machining operation - rough (BLUE) and finish (RED) drilling operations
  - ***Option* B** -- Produce the holes with a rough diameter using four sand cores in the mold. The sand cores are removed from the casting and the holes are finish drilled (RED).

Which option would you choose (Option A or Option B)?





Option A -- Two Step Machining



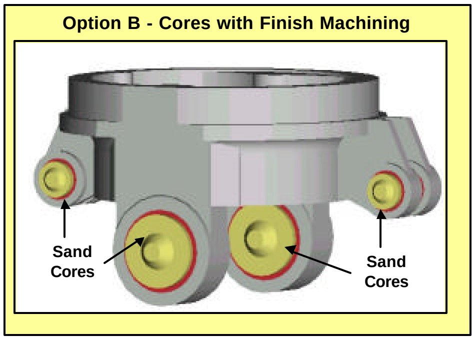
- In Option A the holes are produced in the tabs by a two step machining process -- rough drill (*Blue)* and finish drill (*Red).*
- A comparative cost analysis showed that for this component and the required production rate, the rough drill operation for the six holes was ***less*** expensive than the cost of making and placing the sand cores in the mold.

The two step drilling procedure is more economical for this design and production rate, compared to the alternative method of making and aligning/positioning multiple cores to produce the rough holes in the castings and then doing finish drilling

Option A is the Right design choice.

Go to the Next Design Issue

Option B -- Cores with Finish Machining



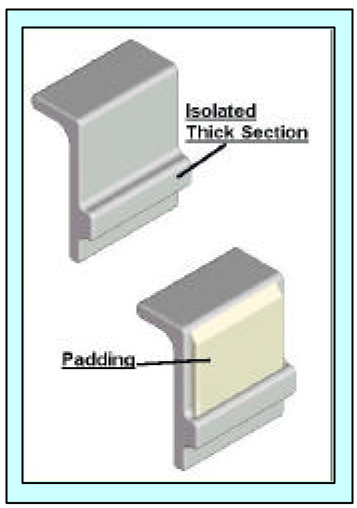
- In Option B the holes are produced in the tabs by using four cores to introduce undersized holes in the coupler. Using the cores will eliminate the rough drill requirement for the holes.
- Since the holes have a tight dimensional requirement, the holes will still have to be finish drilled.
- A comparative cost analysis showed that, for this component and the required production rate, the cost of fabricating and placing the cores in the mold was more expensive than the rough machining step.

Option B is NOT the best design choice.

Go Back to the Options Page

Reducing Isolated Hot Spots

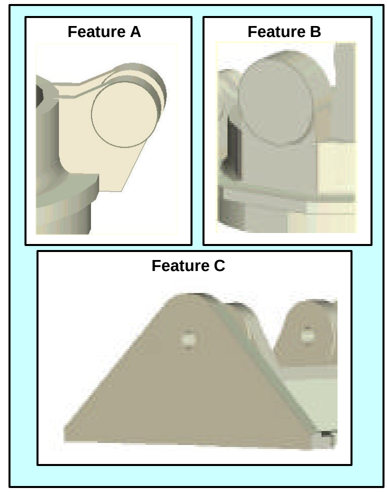
- **In evaluating a component design, the casting engineer looks for isolated thick sections which could be "hot spots" where shrinkage porosity or "hot tears" might form.**
  - **As metal in thin sections solidifies first, the thicker section will be isolated from the molten feed metal and shrinkage porosity can form in the thick section.**
  - **The thin connecting section into the thicker section should be "padded" to improve the thermal connection and metal flow into the "hot spot".**



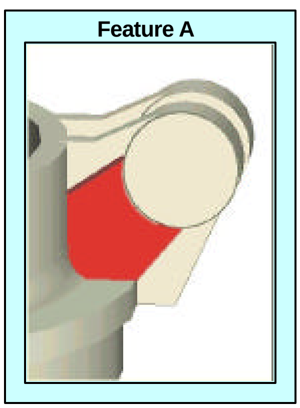
Reducing Isolated Hot Spots

- **The drawings to the right show three thick sections on the plates.**
- ***Choose*** **those features where padding is needed to prevent an isolated hot spot.**
  - ***Feature A*** -- Small tabs - The wall section connecting the small hinge knuckle to the ring in the bearing plate
  - ***Feature B*** -- Large tabs - The wall section connecting the large hinge knuckle to the ring in the bearing plate
  - ***Feature C*** --. The hinge flange plate extending out from the hinge base plate.

Which features (A, B, or C) would you choose ?



Feature A - Small Tabs on the Bearing Plate



Feature A, the circular knuckles (4"∅) on the small tabs are 1.6" thick to provide strength and stiffness. The walls connecting the tabs to the main ring are 0.86" thick.

- The difference in thickness between the tabs and the connecting wall will produce a hot spot.

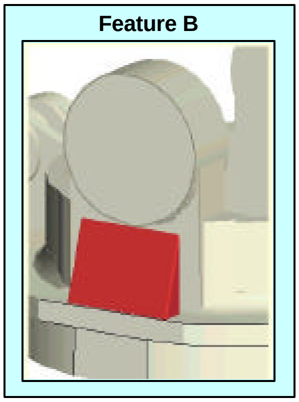
The drawing shows the feed pads ***(in red)*** added to the walls to prevent thermal isolation and promote metal feed into the knuckle section.

- The pads also serve to stiffen and strengthen the small tabs.

Feature A does need padding to eliminate a hot spot.

Go to Feature B or C
Or Go on to the Next Design Issue

Feature B - Large Tabs on the Bearing Plate



Feature B, the larger circular knuckles(8"∅) on the large tabs are 3.2" thick to provide strength and stiffness for the main pivot pins. The walls connecting the tabs to the main ring are 3.0" thick.

- The mass of the large tabs and their distance (9") from the main ring call for the use of a feed pad.

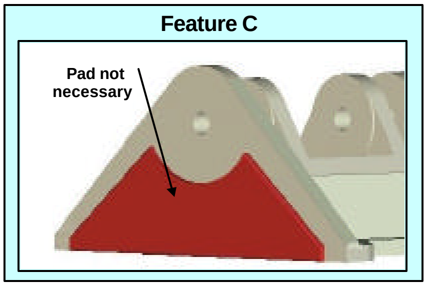
The drawing shows the feed pad ***(in red)*** added to the wall to prevent thermal isolation and promote metal feed into the tab section.

- The pads are ground off after casting, because they would interfere with fitting and articulation between the two plates.

Feature B needs padding to eliminate the hot spot.

Go to Feature A or C
Or Go on to the Next Design Issue

Feature C - Flange Section on the Hinge Plate



Feature C, the flange plate on the hinge plate, is approximately 1.5" thick, 13" long, and 35" wide at the base.

With the triangular shape and the pivot rod hole on the end of the plate, a "hot spot" is unlikely to develop in this section.

The picture shows a proposed pad, but ***no*** padding is necessary on the flange section of the hinge plate.

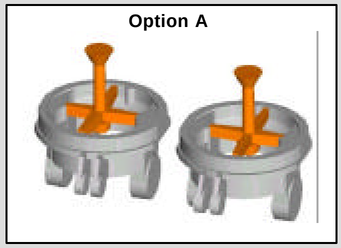
Feature C does not need padding to prevent an isolated hot spot.

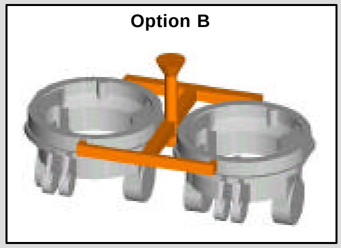
Go to Feature A or B
Or Go on to the Next Design Issue

Design of the Gating System

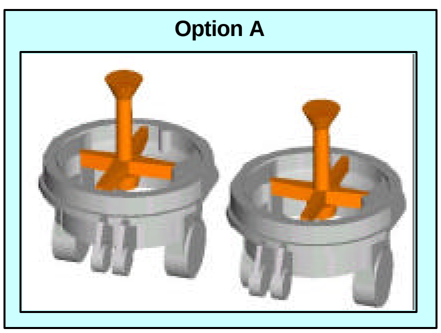
- The gating system (downsprues, runners, and ingates) serves as the flow path for molten metal into the mold cavity.
- Proper design of the gating system is critical to provide for uniform, controlled metal flow
  - Non-uniform, long path, and/or slow metal flow may produce unfilled sections or solidification shrinkage in the casting.
  - Excessively rapid metal flow or metal splashing will cause turbulence and produce oxidation of the steel.
- The bearing plate is cast in a "2-on" pattern in the flask.
- **Two gating systems for the bearing plate are shown in the drawing to the right.**

Choose the gating system (Option A or Option B) which provides the shortest, most direct flow into the mold.





Option A - Two Center Sprues and ID Gating

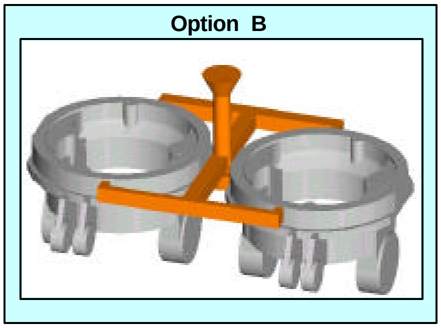


- In Option A, the gating system consists of two sprues (one for each bearing plate) with runners and ingates feeding metal directly into the inner diameter and the four quadrants of the plate.
- This gating system design provides the shortest metal path and the most direct feed into the mold. It will --
  - Insure uniform and complete filling of the the mold cavity.
  - Avoid turbulence and oxidation in the metal flow.

Option A is the preferred gating system design

Go to the Next Design Issue

Option B - One Center Sprue and OD Gating



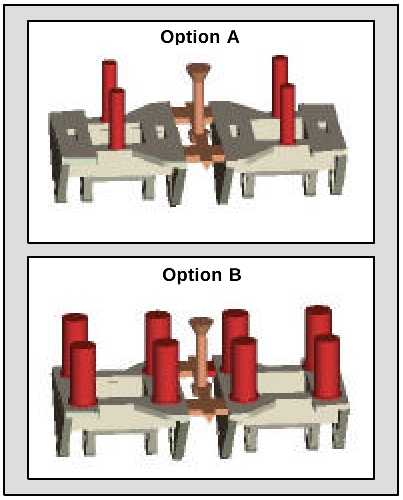
- In Option B, the gating system consists of one center sprue for both bearing plates with runners and gates feeding metal into the outer diameter on two sides of each ring.
- This gating system design has an unnecessarily long metal flow path which could --
  - Produce non-uniform and incomplete filling of the mold.
  - Introduce turbulence and oxidation in the metal flow.

Option B is not the best gating system design

Go Back to the Options Page

Design of the Riser System

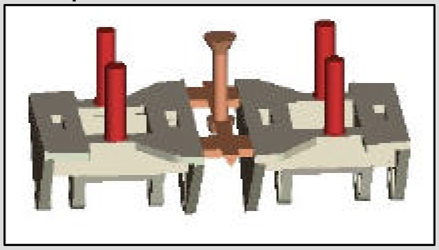
- The risers in the top mold (the cope) serve as reservoirs to feed molten metal into the casting and to prevent solidification porosity.
- Proper design (location, number, and size) of the riser system is critical to prevent porosity caused by solidification shrinkage
  - The risers must provide metal feed into the heavy sections of the casting which are the last to solidify.
  - Solidification modeling is often used as a tool to size and place the risers.
- The hinge plate is cast in a "2-on" pattern.
- **Two riser systems for the hinge plate are shown in the drawing to the right.**



Choose the riser system (Option A or Option B) which provides the best feed into the heavy sections of the hinge plate

Option A - Two Risers on the Hinge Plate

Option A - Two Risers on a Plate



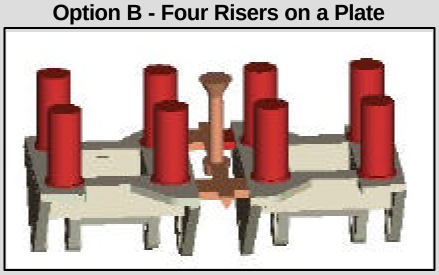
- In Option A, the riser system consists of two small risers for each plate, positioned over the side walls of the hinge plate.
- This riser system design **<u>does not</u>** feed enough molten metal into the heavier sections (the four corners) of the casting. It risks -
  - Solidification shrinkage porosity in the corners.

Option A is not the preferred gating system design

Go Back to the Options Page

Option B - Four Risers on the Hinge Plate

Option B - Four Risers on a Plate



- In Option B, the riser system consists of four large risers for each plate, positioned over the corners of the hinge plate.
- This riser system design provides molten metal feed directly into the heavier sections (the four corners) of the casting. It will prevent
  - Solidification shrinkage porosity in the corners.

Option B is the preferred gating system design

Go to the Next Design Issue

Bearing Plate --

Final Design of the Cope and Drag Patterns

Cope Pattern for Bearing Plate

Drag Pattern for Bearing Plate

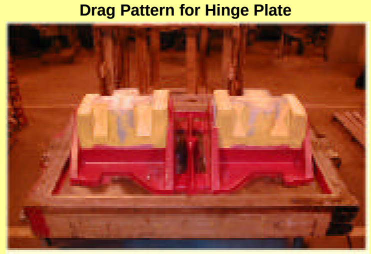
- The photos show the patterns for making the cope and drag molds for the bearing plate. The mold design uses a horizontal parting line on the ring.
- The mold is a “2-on” design with two separate pours, one for each casting. Molten metal flows down each center sprue *(white cylinders in the cope*) and spreads through four gates into each cavity.
- There are four risers positioned over each casting in the cope mold. *(The full height risers are not shown on the cope pattern, only the base posts on which they sit)*
- The tabs sit facing down in the drag mold. Four cores produce the tab features on each plate.The yellow cores are positioned to show their placement in the drag mold

Hinge Plate --

Final Design of the Cope and Drag Patterns

Cope Pattern for Hinge Plate

Drag Pattern for Hinge Plate



- The photos above show the patterns for making the cope and the drag molds for the hinge plate. The mold design uses a horizontal parting line along the main plate.
- The mold is a “2-on” design producing two castings for each pour. Molten metal feeds down a single center sprue and feeds through two gates into each plate.
- There are four square risers positioned over each plate and shown in the cope photo.
- The side walls face down in the drag mold. Three cores produce the center cavity and the two inner flange walls for each casting. The yellow cores are positioned to show their placement in the drag mold

Bearing Plate -- As Cast

Picture of As-Cast Bearing Plate

- After solidification is complete, the casting is -
  - ***Removed from the flask and cleaned of sand in the shake-out process***
  - ***Surface cleaned by shot blasting***
  - ***Cut and trimmed to remove the rigging and the extra feed pads***
  - ***Finish trimmed by grinding***

Hinge Plate - As Cast

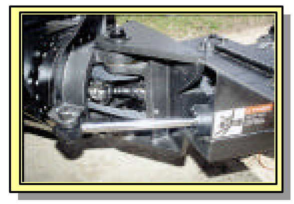
Picture of As-Cast Hinge Plate

- After final cleaning, the castings are checked for dimensional tolerances and prepared for three finishing operations --
  - ***Heat treated to normalize the microstructure and mechanical properties***
  - ***Non-destructively evaluated by dry powder magnetic particle inspection***
  - ***Packaged for shipping to the outside machine shop***

The Lessons Learned

With the successful production of the hinge plate and bearing plate over the last 5 years, there were two important lessons learned in this redesign and production effort.

- *Concurrent engineering between the foundry and the buyer was critical for meeting quality, cost, and schedule goals.*
- *Close communication between the design engineers and Grede foundry engineers was the key to redesign of the castings to optimize performance benefits and castability.*



Summary --
Casting the Hinge/Bearing Assembly

- *The hinge-bearing assembly in the Log Forwarder was converted to two steel castings produced in sand molds with --*
  - *Improved durability,*
  - *15% weight savings*
  - *Reduced manufacturing cost.*

For further information on the design and production of this and other steel castings, contact -- **Bob Mueller Jr.** at the **Grede, Milwaukee Steel Division**
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