ATTACHMENT 4

STRESS ANALYSIS OF THE KSV-4-2A MASTER CONNECTING ROD

Cooper-Bessemer Reciprocating Products Division
Cooper Industries, Inc.

Applied Mechanics Report
AM-1852-C

Stress Analisis of the KSV-4-2A Master Connecting Rod

Prepared by:

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Grove City, PA

February 4, 1987

History

The KSV master connecting rod was originally designed in 1957 and is similar to the LSV rod which dates from 1948. Because of the sucessful history of the LSV, no stress analysis work was done on the KSV design, other than routine calculations for the upper shank and cap bolt sizing. The present KSV-4-2A rod design is structurally identical to the original KSV rod. The only modifications made in the 30 year history of this rod design have been the elimination of bearing shims and the lube oil check valve, and changes in tolerancing to reflect current manufacturing practices.

To our knowledge, there have been no structural failures of the KSV master rod until the December 1986 occurance at Arizona Public Service. This failure has been traced to the presence of electroplated iron with a low resistance to fatigue at a stress riser in the rod. In spite of that fact, it was decided to perform a finite element stress analysis on the rod to quantify the stress levels of this design. This report covers the results of that analysis.

Loading

The total loading on this master rod can be divided into three catagories; assembly, firing, and inertia. The assembly load is due to the interference fit of the crankpin bearing shells in the rod, producing a nominal radial pressure of 833 psi in the crankpin bore of the rod. Firing loads always act in a downward direction, and thus are transfered directly to the crankpin in the area closest to the load application. These loads produce relatively low compressive stresses in the lower portion of the master rod, in a direction normal to the bearing surface.

Inertia loads, on the other hand, act in both upward and downward directions. The peak downward inertia loads occur near the bottom center position of the crank throw, and produce stresses similar to those from the firing loads, but lower in magnitude. The peak upward inertia forces occur near the top center position of the crank. Their reactions occur in the lower half of the crankpin bearing, so that tangential stresses are produced in the art pin bales and around the crankpin bore of the master rod as the loads are transferred to the bearing reaction area. Since the KSV is a "4 Stroke Cycle" engine, the peak upward inertia forces occur twice in the complete power cycle of each cylinder, at the end of the exhaust stroke and again at the end of the compression stroke. On the exhaust stroke the pressure on the piston is very low, so the net load is upward and very nearly equal to the inertia load. On the compression stroke, the force from compression pressure at top center is equal to or greater than the inertia force, so the net load is zero or downward. The two cylinders on any crank throw fire on altenate revolutions of the crankshaft, so there is no significant interaction between the peak upward loads of the two cylinders. The maximum upward inertia load from either cylinder will be 44.6 kips at 600 rpm, and 54.0 kips at the 660 rpm overspeed trip setting.

Procedure

A two dimensional plain stress finite element model of the lower portion of the master connecting rod was developed as shown in Figure 1. The thickness of each element was set equal to the actual metal thickness in that portion of the rod. A two-dimensional model is valid in this case because all loading and all significant stresses are in the plane of the model. The crankpin bearing shell and articulating pin bushing were not included in the model. The model was analysed using the IFAD computer code, version 2.001, written by Applicon Division of Schlumbergor Systems, Inc., and installed on our VAX computer system. The following load cases were analysed:

1. Assembly load only - A uniform radial pressure of 960 psi was applied to the crankpin bore. This value was choosen to encompass the high limit of the interference fit between the crankpin bearing sheel and the rod.

2. Master bank upward inertia only - The model was held at the cut line on the shank and a distributed pressure load applied to a portion of the crankpin bore directly opposite the shank. The pressure load was adjusted to product a total tension force of 54.0 kip in the shank.

3. Articulating bank upward inertia only - The model was held at several nodes in the crankpin bore directly opposite the articulating pin bore, and a distributed pressure load was applied to the inside of the articulating pin bore in the bale area. The pressure distribution was adjusted to produce a total upward force of 54.0 kips along the axis of the articulating rod, and to produce a deflection pattern in the bale area such that the radius of the pin bushing would conform to the slightly smaller radius of the pin.

4. Combined assembly and master bank upward inertia loads.

5. Combined assembly and articulating bank upward inertia loads.

In each case a post processor computer code was used to search the complete mode stress output for the largest values of maximum and minimum principal stress.

A Modified Goodman Diagram procedure was used to calculate the Cyclic Failure Factor (safety factor against fatigue failure) in the critical areas of the model. In all cases the dynamic portion of the maximum principal stress was assumed to vary from zero to the maximum calculated value, and stress concentration factors were applied to the dynamic stresses where appropriate. Stresses for the 600 rpm (44.6 kip inertia load) case were obtained by proportioning the 660 rpm results.

Results

For the combinded assembly and master rod inertia loading the minimum Cyclic Failure Factor (CFF) will occur at location A on Figure 1, based on a stress concentration factor of 2.0 for the oil hole between the crankpin and articulating pin bores. The CFF values at this point are 2.98 at 600 rpm and 2.56 at 660 rpm, based on the minimum specified physical properties of the ASTM A-521, Class CG rod material.

For the combined assembly and articulating rod inertia loading, the minimum CFF will occur at location B on Figure 1, based on a stress concentration factor of 2.0 for the fillet radius where the bales join the full section of the rod. The CFF values at this point are 3.10 at 600 rpm and 2.51 at 660 rpm. The maximum stresses in the uniform portion of the bales occur at location C, with CFF values of 4.00 at 600 rpm and 3.29 at 660 rpm.

The stresses at locations A, B and C are shown on a modified Goodman diagram for the rod material in Figure 2.

Conclusion

The minimum Cyclic Failure Factors at all locations in the lower part of this master connecting rod are well above our design value of 2.25, under both the normal operating and the overspeed trip setting conditions. Thus the design is more than adequate for normal operation and has ample safety margin to cover occasional unforeseen loading conditions or minor machining deviations.

John M. Horne

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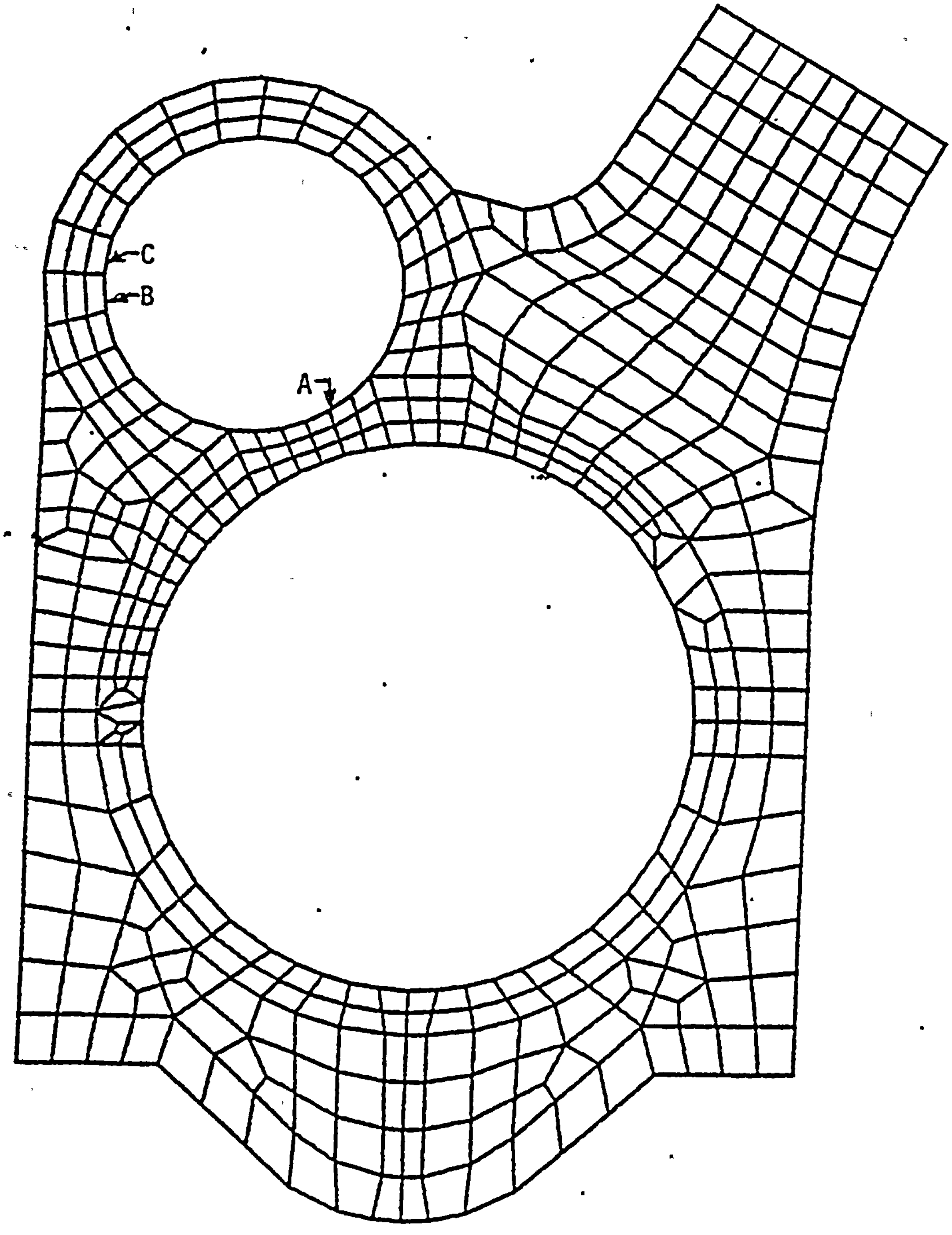
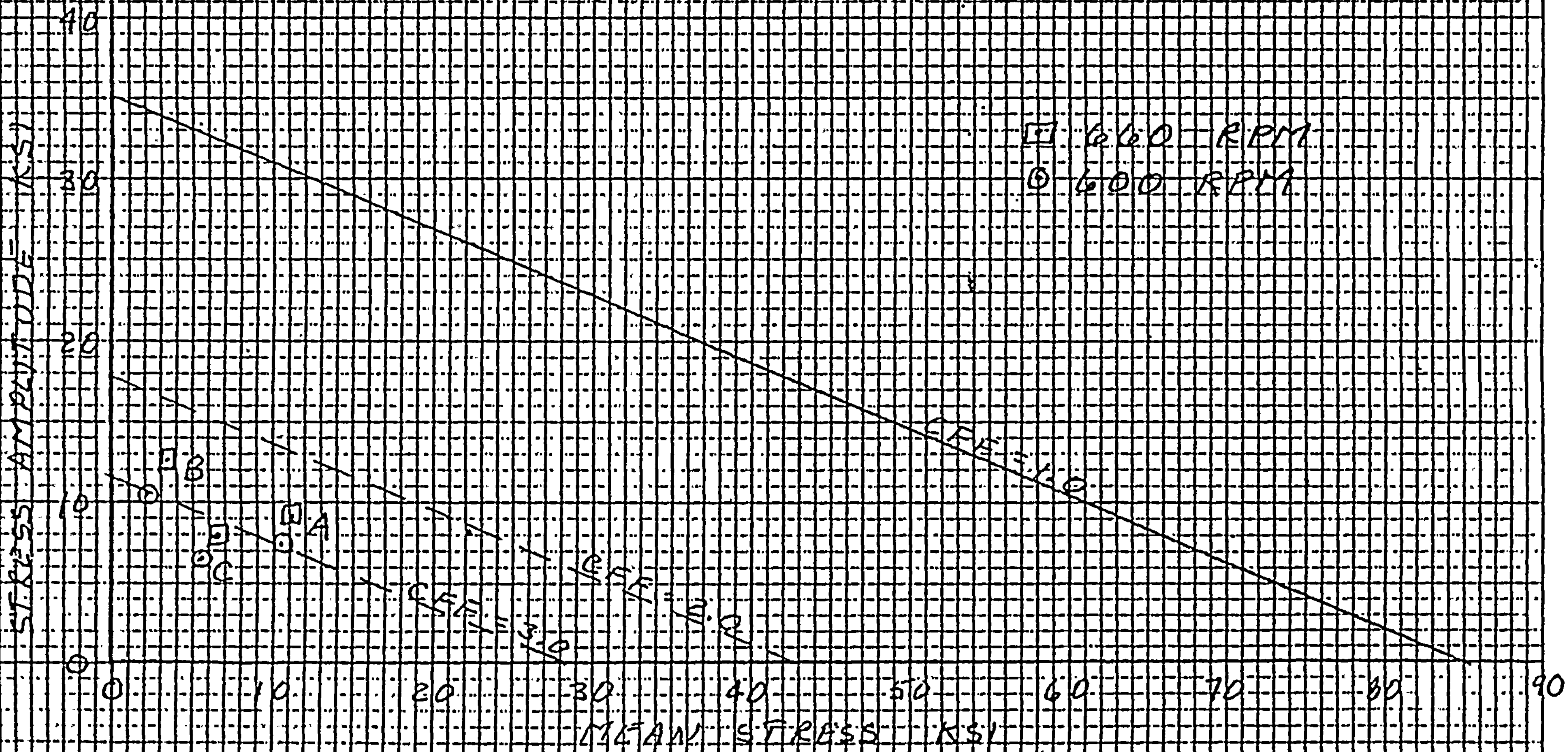


Finite Element Model and Maximum Stress Locations
KSV-4-2A Master Connecting Rod
AM-1852-C
Figure 1

MODIFIED GOODMAN DIAGRAM
KSV-4-2A MASTER CONNECTING ROD
COOPER-BESSEMER MATERIAL SPEC. C5B
ASTM-A-521 CLASS CG



AIM-1852-C FIG 2 MH 1-30-87

ATTACHMENT 5

ARTICULATED ROD STRESS STATEMENT

TELECOPY

DATE March 12, 1987

TO Arizona Public Service
Phoenix, AZ

ATTN Frank Honer

FROM John Horne

SUBJECT Palo Verde Unit 3-B Diesel Generator

In response to the NRC Staff Recommendations which were attached to George Knighton's letter telecopied to us on March 9, 1987, we have the following comments:

Item 1. Our report AM-3423 covers the torsional analysis requested. We feel a torsiograph test of the repaired 3-B diesel generator is unnecessary because an identical unit was torsiographed in 1978 and the change in torsional characteristic due to the repair is insignificant.

Item 2. The finite element analysis of the large end of the master connecting rod is covered by our report AM-1852-C. We have not done a similar analysis for the articulated rod since the stresses in this component are rather straight forward. The design of the high stress area of the articulated rod has been verified by strain gage testing on similar designs, and we have never experienced a failure of a KSV articulated rod.

In response to the second sentence on Item 2, we know of no influence that torsional vibrations would have on the critical stresses in the connecting rod.

Item 5. This question is answered in Attachment 2 to report AM-3423 in Item 1.

Item 12. The high stress areas in the lower end of the master connecting rod are identified in report AM-1852-C. Other high stress areas are shown on page 8 of QCG-3385.

<u>General</u> :

A discussion of the effects of engine operating loads on the repaired centerframe and block castings can be extracted from the first two paragraphs of my February 5, 1987 report on seismic analysis of the repair components.

If we can be of further assistance, please let me know.

Sincerely,

John M. Horne

John M. Horne, Manager
Analytical and Compressor Engineering

JMH/sas