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O T T A W A   November 5th, 1943.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1527.

Examination of a Steel Generator Shaft
Which Failed Prematurely in Service.

(Copy No. 10.)

Bureau of Mines
Division of Metallic
Minerals
-
Ore Dressing
and Metallurgical
Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

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Which Failed Prematurely in Service.

Origin of Sample and Object of Investigation:

On November 2nd, 1943, a letter (File No. N.S.858-3-43 FD2111B (Staff)), covering a section of a keyed generator shaft earlier delivered to these Laboratories, was received from Lieut.-Comm. J. R. Millard, Director of Technical Research, Department of National Defence, Naval Service, Ottawa, Ontario. It was reported that this shaft, said to have been manufactured from SAE 1035 steel, had failed after 12 hours of service. Request was made for an examination to determine, if possible, the cause of failure.

Chemical Analysis:

Drillings from the shaft were chemically analysed, with the following results:

		Per cent
Carbon	-	0.35
Manganese	-	0.77
Silicon	-	0.16
Sulphur	-	0.028
Phosphorus	-	0.019
Nickel	-	0.04
Chromium	-	0.95
Molybdenum	-	0.01

Macro-Examination:

A general view of the sample received is given in Figure 1.

Figure 1.

(Approximately 2/3 actual size).
Note: Some samples for microscopic examination were removed before this photograph was taken.

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The fracture appears to be of the duplex fatigue type but its exact nucleus was not ascertainable.

It is understood that in service a fitting is shrunk

(Macro-Examination, cont'd) -

onto this end of the shaft. Since the metal near the failure had dark tempering colours, the temperature employed in this operation must have been fairly high. The keyway in the part (see Figure 1) apparently is an additional insurance against slip.

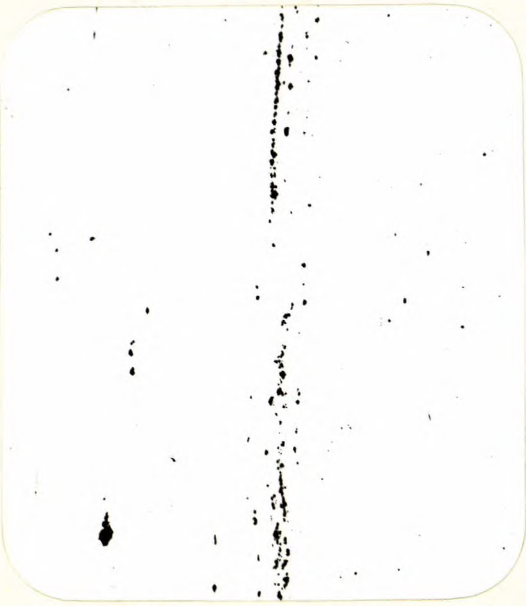
The Vickers hardness (10-kilogram load) of this sample was 182-206 V.H.N. These readings are approximately directly convertible to Brinell values.

Micro-Examination:

Two samples for microscopic examination (one of them near the point of failure) were removed from the shaft, mounted in bakelite, and polished.

Figure 2, a photomicrograph of the unetched steel near the point of failure, shows that it is very dirty. After an etch of 2 per cent nitric acid in alcohol had been applied, the structure was seen to consist of pearlite and ferrite (see Figure 3).

Figure 2.



X100, unetched.

Figure 3.

X100, etched in 2 per cent nital.

Discussion of Results:

The results of the chemical analysis show that the steel in this shaft is SAE 5135 rather than SAE 1035. The added chromium would certainly increase the hardenability but, since the shaft was not given a quench-and-draw heat treatment, its effect on fatigue properties would probably not be appreciable.

The high temperature used in shrinking the fitting onto this shaft could indicate either (a) that the shrunk-on part was considerably smaller in diameter than the shafting or (b) that an unnecessarily high temperature was used (with the correct allowance in diameters), so that the presence of tempering colours is not conclusive evidence that the shafting was unnecessarily highly stressed compressively near the point of failure. It is certain, however, that when a fitting is shrunk on, clamping stresses, which would result in a stress concentration close to the junction of the fitting and the shaft, will be exerted. Since this failure occurred near the junction, these stresses may well have contributed to the failure.

The sharp changes of section characterizing the keyway in this shaft would result in stress concentrations. Large inclusions present in the metal would have a similar effect.

The following quantitative figures, in pounds per square inch, on the effects of keyways and clamping stresses on the endurance limit of a steel of 60,000 p.s.i. tensile strength, are quoted from "Prevention of Fatigue of Metals" (Battelle Memorial Institute), 1941 edition, Page 64:*

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* The original experiment by A. Thum appeared in 1935, in the discussion on "Relation of Fatigue to Modern Engine Design", a paper by R. A. MacGregor, W. S. Burn and F. Bacon. (Trans. North East Coast Inst. Eng. and Shipbuilders, Vol. 51, 1935, pp. D122-D123).

(Discussion of Results, cont'd) -

		Rot.-beam endurance limit, not clamped	Rot.-beam endurance limit, clamped
Plain round shaft, unnotched	-	35,000	18,500
End-milled for plain parallel key, end-rounded as to width	-	20,500	15,000
Face-milled for parallel key, sled-runner ends	-	28,000	13,500

Microscopic examination (by revealing the presence of considerable areas of ferrite) definitely shows that the part was normalized (air cooled) rather than quenched and drawn. Since this air-cool heat treatment left the steel in a comparatively soft condition, its fatigue-resisting properties are at a practical minimum.

CONCLUSION:

Failure was caused by clamping stresses, and stress concentrations resulting from the keyway and the inclusions in the steel, acting in conjunction with regular service stresses. A quench-and-draw treatment rather than a normalizing treatment for the steel would be expected to considerably improve performance. In this treatment the part should be quenched from the draw to avoid temper brittleness. Shotblasting should also lead to improvement of service.

RECOMMENDATIONS:

1. If a fully heat-treated, more highly alloyed steel is not available, the steel at present in use (SAE 5135) should be given a quench-and-draw heat treatment (with a quench following the draw), so that its final hardness is somewhat higher

(Recommendations, cont'd) -

than at present (possibly 250-275 V.H.N.). This hardness is mentioned because it is understood that machining is to be done after heat treatment. The inclusion content of the steel should be lessened.

2. A mechanical attachment arrangement should be substituted for the shrink fit procedure now used, as present practice leads to high stress concentration. As the hardness of the steel in the shaft increases this condition is aggravated due to the increase in notch sensitivity to this stress concentration. As a result, the potentially beneficial effect of heat treatment on the endurance limit may be nullified. The keyway used in this shaft should preferably be of the sled-runner type.

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