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INVESTIGATION OF THE FAILURE OF A SHEAVE WHEEL AXLE FROM SHAFT #4, V.C. McMANN LTD., MINTO, N.B.

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

The failure of a sheave wheel axle in service was found to be due to fatigue, the crack originating in a keyway. Recommendations are made for changes in the design or material specifications of the axle.

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INTRODUCTION

On November 9, 1960, a fracture in the hoisting sheave wheel axle at shaft #4, V.C. McMann Ltd., Minto, N.B., resulted in a loaded cage falling to the bottom of the shaft, causing extensive damage to the cage and parts of the hoisting mechanism. Subsequently, on May 1, 1961, a request for evaluation of the failure was received from the Mine and Inspection Engineering Division, Department of Lands and Mines, Province of New Brunswick (their reference GFC/mv).

The axle, which was made of an unspecified steel, was received in two pieces, the fracture having occurred close to the end of the keyway used for location of the sheave wheel on the axle (Figure 1). The length of the axle was 21 in. and, from markings on the axle, it was deduced that the bearing length at either end was 6 in. The diameter of the axle in the bearings was approximately 2 3/8 in., and that of the centre section locating the sheave was $2\frac{1}{2}$ in.

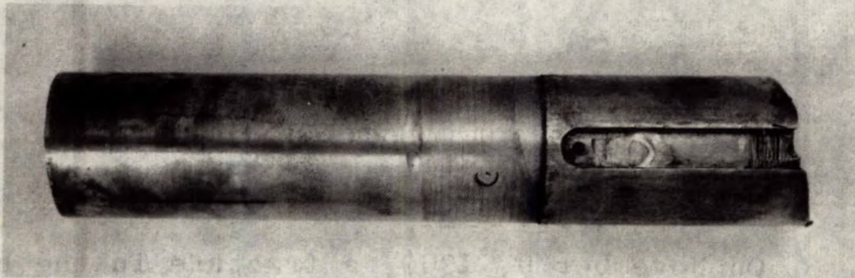

Figure 1. Part of Failed Axle Showing Keyway.

VISUAL EXAMINATION

The fracture (see Figure 2) can be considered as typical of failure by fatigue under conditions of rotating bending. The characteristic markings of a fatigue failure are particularly noticeable on the right-hand piece in Figure 2, originating from the vicinity of the left-hand bottom corner of the keyway. The keyway itself had some very pronounced scoring marks at the bottom (Figure 3), but it is considered by the mine foreman that these were caused during disassembly of the unit after failure. However, in the absence of positive evidence to support this, the possibility of operation with a loose key cannot be eliminated.

The fracture itself passed through a drilling tip at the end of the keyway, but close examination of the fracture did not suggest that the failure had, in fact, been nucleated at this point.

Figure 2. Fracture Surfaces

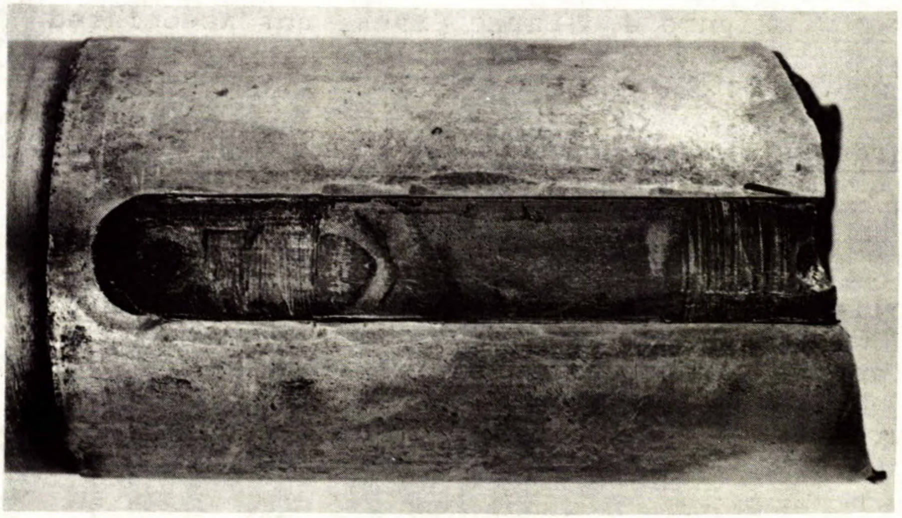

Figure 3. Keyway of Axle

Examination of the axle surface in the section containing the keyway showed a large crack running around approximately one-quarter of the circumference (Figure 4). As this crack was not directly associated with the fracture, it could only have had a minor effect on the failure of the axle caused by modifications to the stress distribution pattern within the wheel fit.

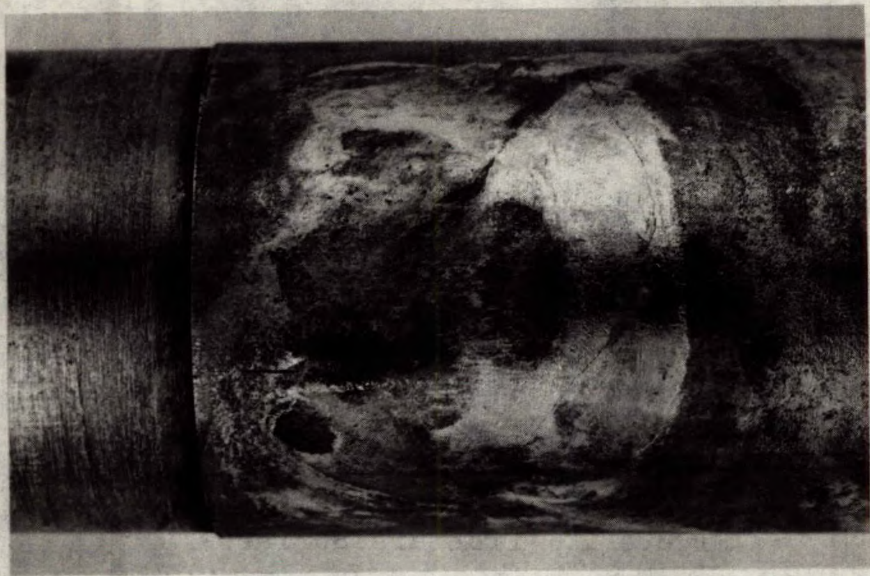

Figure 4. Large Crack, not associated with Failure

Hardness Measurements

Rockwell hardness measurements were made on a polished cross-section taken from a plane close to the fracture. These measurements gave values of R_b85 at the surfaces, decreasing to R_b81 in the centre of the axle.

MECHANICAL TESTS

Six longitudinal $\frac{1}{4}$ in. diameter standard tension test bars were machined from part of the axle. The results of tensile tests on these bars were consistent, showing a mean ultimate tensile strength of 68,800 psi.

CHEMICAL ANALYSIS

Wet analyses of drillings from the axle gave the results shown in Table 1.

Table 1

Results of Chemical Analysis

Element	Concentration (in wt %)
Carbon	0.22, 0.20
Manganese	0.40, 0.42
Phosphorus	0.008
Sulphur	0.023
Silicon	0.04
Chromium	0.02, 0.02
Molybdenum	trace
Vanadium	trace
Nickel	trace

The composition indicated lies within the range covered by SAE standards 1020/1025.

METALLOGRAPHIC EXAMINATION

An examination was made of polished and etched sections taken from several positions in the cross-section of the axle, close to and away from the failure. In all cases the structure was found to be pearlite in a ferrite matrix, which corresponds with the hardness and tensile values previously noted (see Figure 5). Except as noted subsequently, the number, size and distribution of inclusions were within the limits normally accepted for this steel.

Figure 5. Typical Photomicrograph of Cross-Section

Etched in 2% Nitric Acid in Ethyl Alcohol

X100

A micro-section of the keyway, taken very close to the fracture, was examined, and, in one corner corresponding to the position of the indicated origin of the failure, evidence of inadequate machining was found (Figure 6).

Figure 6. Section of Keyway near Fracture

Etched in 2% Nitric Acid in Ethyl Alcohol

root face

X17

It appears that a cutting from the keyway root has not been completely removed, and has been folded over and forced into the corner. It is certain, from visual examination of the unit, that this did not occur on disassembly, but it is not clear whether the cutting was forced into the position noted during the final machining operation, or whether this occurred during initial assembly of the unit.

An examination of a section of the keyway taken from a position further away from the apparent site of nucleation showed that, in this position, the keyway was machined cleanly. However, the root and sides formed an extremely abrupt corner, with a fillet radius of 0.015 in. or less.

DISCUSSION

From figures supplied by the mine foreman, it can be estimated that the weight of a loaded cage in this operation is 5,000 lb overall. If the assumption is made that the axle is uniform with freely supported ends at the centre of the bearings, the maximum working stress is 13,100 psi. It should be emphasized that this is not the stress at all times during operation, as hoisting with an empty or partly loaded cage would result in lower values. From figures supplied, it is estimated that, since installation, the axle under study had undergone about 1,000,000 rotations under full load, and up to 1,500,000 cycles under lesser loading.

This approximate analysis ignores the tension in the rope leading to the engine room; the effect of this tension will be to increase the working stress above the level quoted.

Calculations on the same basis as those already stated show that, for the loads involved, the clearance between the sheave and the axle would need to be 0.0005 in. with a bearing clearance of less than 0.004 in. in order to accommodate the necessary axle flexure. These clearances are well within the machining tolerances normally found in an application of this nature.

From published data 1/ 2/ on the stress-raising effect of the straight portion of a keyway in a circular shaft, it can be deduced that, with the fillet radius measured, a stress concentration factor of a minimum value of 3.5 for torsion exists in a shaft of the size under study. No comparable data exist for the corresponding factor in bending, but it can be assumed that it will be of the same order as that for torsion.

1/ R.E. Peterson. Stress Concentration Design Factors. John Wiley & Sons, Inc., New York (1953).

2/ M.M. Leven. Proc. SESA, 7, 141, (1949).

For a low carbon steel of the strength found here, the maximum fatigue limit will be of the order of 35,000 psi. As a maximum working stress of about 13,000 psi exists without any keyway effect, it can readily be seen that a stress concentration factor of somewhat over $2\frac{1}{2}$ would be sufficient to move the component into a stress range liable to produce fatigue failure. It is considered that under the service conditions the stress concentration factor will be greater than this, possibly as high as the 3.5 value noted for torsion.

There is no information available as to the effect of poor machining of the root (Figure 6) on the overall stress concentration factor of the keyway. However, as the failure appeared to originate in this region, it may be concluded that the poor machining resulted in even higher local stresses than would otherwise have existed.

It must be noted that even with a large radius fillet in the keyway root, of the order of 1/8 in., the stress concentration factor will still be greater than 2. It is apparent that, even using a correctly machined keyway with adequately radiused fillets, the factor of safety with the present material will be rather low. It is therefore desirable for satisfactory service to either redesign the component or change the material specification.

The use of an axle of only $\frac{1}{2}$ in. larger diameter (viz 3 in.) will lower the nominal working stress, under the same conditions of shaft length, to a value of 7,000 psi. The use of larger radius fillets is a necessary corollary when using a 3 in. diameter shaft, and a fillet root radius of not less than 1/8 in. is recommended.

If geometrical considerations preclude the use of an axle of larger diameter it is possible to improve the fatigue characteristics of the design by specifying a higher strength steel. A steel of SAE 1340 composition, or a near equivalent, would be satisfactory for this application, providing an ultimate tensile strength of the order of 100,000 psi, while still retaining good machining properties. It is interesting to note that such steels, or even steels of higher strength, are normally specified for axle service of the nature encountered in this instance.

Before conclusion of this discussion, mention must be made of the presence of the unrelated, but large, crack present at the other side of the axle to the keyway (Figure 4). For such a crack to have nucleated, there must have been a stress-raising factor present of the same order as that in the keyway. A section containing the crack was cut from the axle, and machined to expose the surface of the crack. The crack, at its deepest penetration into the axle, was typical of a fatigue failure; closer to the axle surface the crack was smoother and had a brighter surface (Figure 7). A detailed examination revealed the presence of some dark coloured powder in a crevice of this crack near the surface of the axle. On X-Ray analysis, the powder proved to be Fe_2O_3. This oxide is frequently encountered in the outer layers of scale on steel, and it seems probable that the inclusion originally present was caused by some defect present during the rolling process. In service, fatigue had originated from this inclusion.

Figure 7. Surface of Crack shown in Figure 4.

Approx. X2

CONCLUSIONS AND RECOMMENDATIONS

(1) Failure of the axle was by fatigue, the crack originating in a keyway.

(2) The keyway had an inadequate root fillet radius, and was not properly machined.

(3) It is recommended that either a shaft of larger diameter and keyway root radius be used, or a steel of higher strength be specified.

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