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MINES BRANCH INVESTIGATION REPORT IR 66-57

# FAILURE OF FLAT STEEL SPRINGS USED IN VIBRATING TABLES

by

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PHYSICAL METALLURGY DIVISION

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# FAILURE OF FLAT STEEL SPRINGS USED IN VIBRATING TABLES

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W.M. Crawford* and M.J. Nolan**

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## SUMMARY OF RESULTS

A metallurgical examination was carried out on flat steel springs which had failed in service in a train of vibrating tables.

Chemical analysis showed the material to be a plain carbon steel containing 0.86% carbon. Metallographic examination disclosed the microstructure to be of lamellar pearlite typical of a normalized condition. Brinell hardness tests gave readings of 293, corresponding to a tensile strength of about 145,000 psi.

Welding of this type of steel was not recommended.

Failure occurred by fatigue and was probably aided by a stress-concentration at the cross-member bolt hole.

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# INTRODUCTION

In a letter dated March 22, 1966, a request for assistance from the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, was made by Mr. H. Hahn, Plant Engineer of Hershey Chocolate of Canada Ltd., Smiths Falls, Ontario. The problem concerned the failure of flat steel springs used in a train of vibrating tables. On a visit to the Physical Metallurgy Division on April 6, 1966, Mr. Hahn delivered two of the fractured flat springs and gave detailed information on the problem. These failures had occurred subsequent to the original fracture being welded and meant that an assessment of the primary fracture could not be made. On June 1st, 1966, however, a freshly fractured spring was delivered to the Physical Metallurgy Division.

In order to obtain an understanding of the service conditions and discuss the question of welding, a visit was made to the Hershey plant on June 2, 1966, by W.M. Crawford of the Ferrous Metals Section and M.J. Nolan of the Welding Section. It was observed that the vibrating train was made up of 13 pairs of the flat springs placed end to end, each pair being bolted together by a cross-member about 24 inches long. An eccentric shaft acted across the centre of the flat springs and imparted the necessary motion to the chocolate-filled moulds as they passed through on a continuous chain-driven belt. The cross-members were bolted about 14 inches from the centre of each spring and it was primarily in this region that failure was occurring. From an observation of the springs in action, it appeared that the cross-member imposed a restraint on the flexing action. This, in combination with the usual stress-raising effect of a hole in a plate, produced a region of high stress-concentration at the cross-member bolt hole. The degree of vibration was controlled by the speed of the eccentric shaft which, in the section of the train where maximum vibration was required, was set at 1100 rpm. Previously, this had been 1800 rpm and had been reduced in an attempt to cut down failure. It was mentioned that a further reduction in speed of the shaft could not be tolerated since it would adversely affect the production rate. The train was in constant operation 8 hours per day, 5 days per week, which at 1100 rpm amounted to a stress cycling of more than 10 million per month. From these observations it was concluded that, in service, the flat springs were subjected to considerable cyclic stressing, concentrated at the bolt hole for the cross-member attachment, and under an environment which was hot and humid, i.e., conditions very conducive to fatigue failure.

## VISUAL EXAMINATION

The first two springs (Nos. 1 and 2), which had been welded after initial failure and had subsequently failed, are shown in Figure 1. Their general appearance is that of plate 4 in. wide x 3/8 in. thick x 51 in. long with the ends bent under and a series of holes drilled for attachment. Failure in each case had initially occurred through a hole, although in the case of No. 1 plate, the first fracture had stood up after welding and the second fracture occurred through the whole section. Note that both fractures in each plate occurred in the same region, i.e., where cross-member was attached. The surface finish of the drill holes was poor and in some cases the holes had been counter-sunk right through the thickness of the plate resulting in a sharp edge at the bottom. Holes in such condition should be avoided for service in a fatigue environment.

The fractures of these welded joints are shown in Figure 2. The appearance indicated that incomplete welding had occurred and the smooth-surfaced areas suggested that the two fracture faces had been rubbing together. As stated earlier, a true assessment of the nature of original failure could not be obtained from these samples because of the welding. The third sample, however, was untouched after failure and the fracture surface, shown in Figure 3, clearly indicated a fatigue failure which had started at the bottom of the bolt hole. At this point, where the bolt would bear against the plate spring, the surface was deformed and highly polished on the side near the centre of the plate, i.e., where the eccentric shaft acted. This showed that the pieces had been rubbing together for some time after fatigue failure and also indicated that considerable movement by the flexing of the spring occurred at that side of the bolt.

## METALLURGICAL EXAMINATION

Drillings were taken from plate No. 2 and a chemical analysis for the common elements gave the following:

| | Carbon | Silicon | Manganese | Sulphur | Phosphorus |
|---|---|---|---|---|---|
| Per Cent: | 0.86 | 0.22 | 0.39 | 0.036 | 0.002 |

A spectrographic analysis showed only residual alloy content.

A 'Magnaflux' magnetic particle inspection was carried out on the first two plates to determine if any cracks or surface defects were present. Close attention was paid to the area at the holes but nothing detrimental was observed.

Brinell hardness tests were carried out on all three springs and each gave readings in the region of 293. This corresponds to a tensile strength of about 145,000 psi.

A sample, cut from the No. 2 plate, was polished and etched and examined under the microscope. The microstructure (Figure 4), consisted of lamellar pearlite, thus indicating that the steel had not been hardened. Some surface decarburization of about 0.003/0.007 in. was present. In accordance with the sulphur content of 0.036%, many long, elongated, sulphide inclusions were observed.

## DISCUSSION

From the chemical analysis, the material appears to be a normal high-carbon spring steel. The sulphur content of 0.036%, although not unusually high, might be considered rather deleterious for a steel operating under fatigue conditions. Sulphide inclusions act as stress-raisers and the fatigue life decreases with increasing number of inclusions. The strength level of 145,000 psi does not reconcile with the use of a high-carbon content of 0.86%. Metallographic examination of the microstructure confirmed that the steel was in a normalized condition. Normally one would expect a steel of such carbon content to be used in the hardened and tempered condition, and the strength, especially for spring material, to be much higher than 145,000 psi.

Because of the high carbon content, satisfactory welding of this steel is difficult to carry out. The correct welding rod must be used along with the correct temperature for pre-heat and post-heat, followed by the proper heat treatment. Such a job requires the knowledge of specialists with the proper facilities. Welding, however, is not the recommended remedy to fatigue failure. Even if satisfactorily carried out, it would only mean a temporary restoration of the part for it to fail again.

From the frequency of failures, it would seem that the stress acting at the cross-member bolt hole is of the order of the fatigue endurance limit for the material, under the service conditions prevailing at that point. The remedy may lie in a change in design which would reduce stress-concentration effects and/or in a change to a higher strength material that would withstand the present stress system.

Design factors are extremely important where a part is subjected to continuous cyclic stressing and even more so in a hot and humid environment. Holes in a plate are a source of stress-concentration and a rough surface finish to these holes is a further source of stress-concentration. Sharp edges also contribute a stress-raising effect. Thus, an improvement in the present design of flat spring would be to ensure a smooth final surface finish to the holes and to round out any sharp edges.

The inherent fatigue strength of a steel is normally proportional to the tensile strength, and is taken as approximately half, although as pointed out previously, it is reduced by poor design factors and a detrimental environment. The strength of the present material could be increased by an appropriate quench and temper heat treatment. Replacement steel plate of similar composition, i.e., the AISI 1080 series, should be available in Canada from producers such as Algoma, Atlas, Dosco or Stelco, and would eliminate the present inconvenience of having to order from Denmark. An alternative steel with improved toughness in combination with high strength may be in the medium-carbon low-alloy steels such as SPS 245 and Ultimo 4 produced by Atlas Steels Limited. Increasing the thickness of any replacement plate to say 1/2 in. instead of the present 3/8 in., could possibly improve the load-carrying capacity but it could also decrease the flexibility of the spring and increase any stress-concentration effect that was present.

In the processing of any new springs, not only should attention be paid to the surface condition of the drilled holes, but care should also be taken to ensure that surface decarburization during heat treatment is minimal and shot-peening should be carried out afterwards to counteract the decarburization that normally occurs. A protective coating is also important for a material operating under high humidity; therefore, the present practice of coating with aluminum paint should be maintained.

These recommendations for improving the design and strength of the flat steel springs are made assuming the employment of the same operating mechanism in the vibrating train. If, however, the necessary motion can be imparted by a different action that will eliminate the flexing and restraint, then the fatiguing conditions will be removed or substantially reduced and there will be less need for concern about the design factors and strength of the flat springs. A uniform bumping action along the whole length of the plate, utilizing coil springs to provide the return action at the bottom of the eccentric cam, would provide far less severe operating conditions and any fatigue would occur in the coil springs. The latter would probably cause much less inconvenience if they had to be replaced and certainly would be less expensive than the flat steel springs.

## CONCLUSIONS

(1) Failure of the flat steel springs occurred as a result of fatigue.

(2) The material is a plain carbon steel containing 0.86% carbon and because of this carbon content, welding is not recommended.

(3) The steel was in the normalized condition which did not utilize the strength potential inherent in a steel of such carbon content.

## RECOMMENDATIONS

(1) Efforts should be made to ensure that no sharp edges exist at the drilled holes and the final surface finish of the holes is ground smooth.

(2) The strength of the present material may be increased by reheat-treatment i.e., water quench from 1500°F and temper to the desired strength. This steel, however, is susceptible to cracking on severe quenching and the presence of the holes in the plate makes matters worse; therefore, care would have to be taken to prevent this. An oil quench would probably be safer although it may not allow complete hardening through the section. Because of the length of the plates, heat treatment should be done vertically to avoid distortion. A suitable hardness would be in the range 390/450 Brinell.

(3) Replacement material, other than AISI 1080 steel, may be found in a medium-carbon, low-alloy steel such as SPS 245 or Ultimo 4 supplied by Atlas Steels Limited. Such steel would be less susceptible to cracking on quenching.

(4) A reassessment of the type of mechanical action necessary to produce the desired vibration should be made, and consideration given to a change to a mechanism that would eliminate flexing and restraint on the steel plates and would thus remove the prevailing fatigue conditions.

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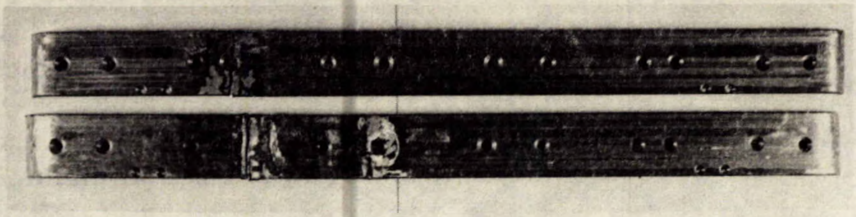

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Figure 1. Photograph showing two flat steel springs (Nos. 1 and 2) received after failure subsequent to welding.

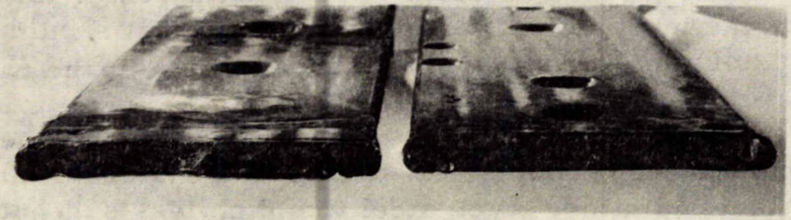

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Figure 2. Photographs of fracture surfaces of the above flat steel springs.

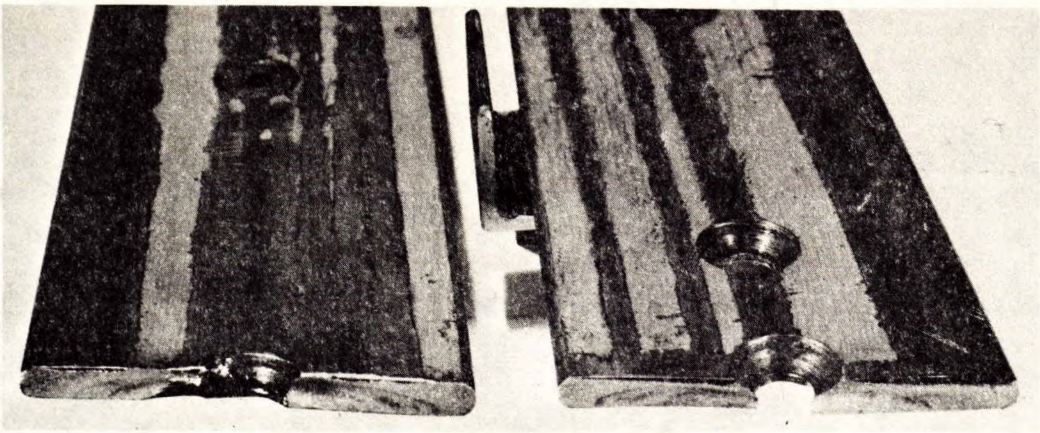

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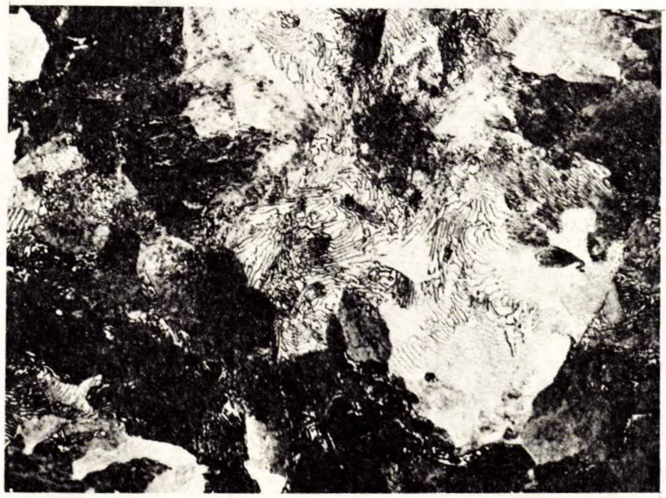
Figure 3. Photograph of fracture surfaces of an original failure (No. 3). Note typical fatigue markings and areas which have been polished as a result of surfaces rubbing together.



X500 Etched in Nital

Figure 4. Photomicrograph of microstructure in No. 2 spring showing lamellar pearlite.