CRACKING OF BUCKET LUGS IN PELTON TURBINES
A CORROSION FATIGUE PHENOMENON

by

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1. Description of Failures.

In recent years the tendency to increased size of generating units has also led to the putting into service of Pelton turbines of increased size and power. Most of the Norwegian plants have used designs with buckets attached to the turbine disc with bolts, either three lug three bolt attachment of Norwegian design or two lug two bolt systems of foreign design. Recently, especially during the winter 1951-52 a number of fractures have occurred in buckets of very large units with two bolt type bucket attachment of foreign design. Following the adoption of more frequent and rigorous inspection a number of cracks have been discovered and the faulty buckets removes before serious damage occurred.

The general form of such pelton buckets is shown in Fig. 1, while figs, 2,3,4, and 5 show examples of failures of the type described

The designers estimate the maximum stresses in the lugs due to centrifugal force and to assumed steady jet force, as follows, in kg/cm²+being tensile—pressure.

	Jet on Bucket	Jet off bucket
Position A	+450	+ 30
,, B	— 70	+430

These stresses are found in an elementary way, neglecting stress concentration, and the actual maximum stresses must therefore be assumed to be considerably higher.

A typical composition of stainless steel used for bucket castings is : 13—14% Cr, 0.2—0.3% C, 0.5% Si, 0.5 % Mn, Ni variable

Mechanical properties:
Max stress 8,000 kg/cm² yield 6,000 kg/cm².
Elongation 10—15% contraction in area 45%
Impact (Charpy) in mkg/cm²
2.7 (20°C) ca. 1.0 (0°C) ca. 0.7 (—20°C)

The cracks seemed to occur preferentially in position B and have the typical appearance of fatigue cracks as can be seen in Fig. 2,3 and 5.

Metallographic examinations so far made are also consistent with this view.

2. Discussion.

The unavoidable conclusion seems therefore to be that alternating stresses on the lugs arising from bucket vibrations have led to corrosion fatigue. It has not been possible to find corrosion fatigue data for this type of steel under test conditions strictly comparable with service conditions, viz. soft mountain water at temperatures from 0°—10°C. However, McAdam* has found corrosion fatigue tests on similar steel compositions in salt spray and fresh water spray not greatly different, while Gough and Sopwith† reported the results

* McAdam Trans. Amer. Soc. Steel Treating, Vol. II, 1927, p. 355

† Gough & Sopwith. J. Iron & Steel Inst., Vol. 127, 1933, 301-322

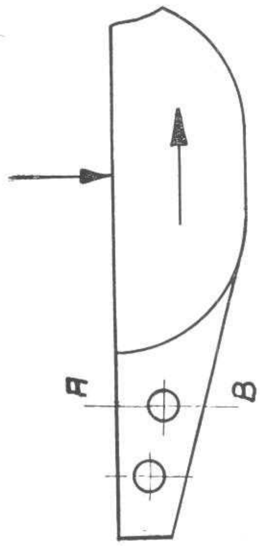

Fig. 1. Pelton Wheel bucket (diagrammatic) showing approximate relative positions of resultant jet and centrifugal forces as well as fixing bolts.

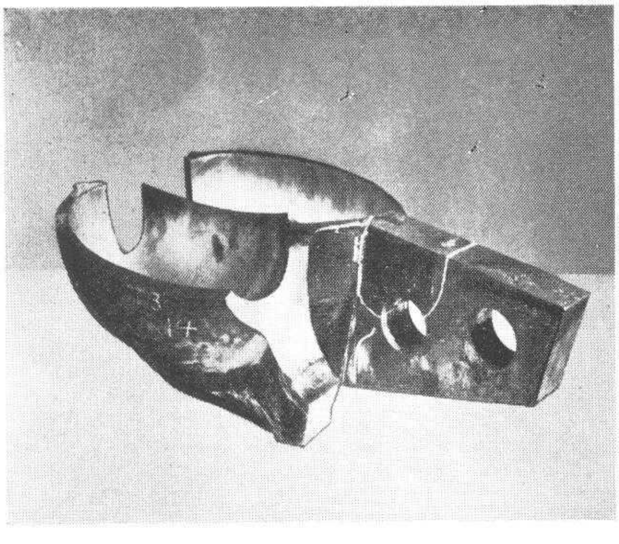

Fig. 2. Bucket fracture discovered January 1952. The turbine was stopped on hearing a knocking noise and the bucket was literally hanging by a thread on the right hand lug while the left hand lug was completely broken.

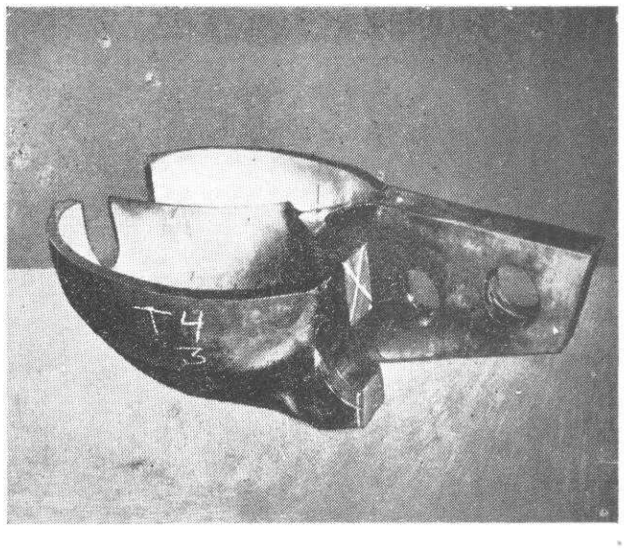

Fig. 3. Bucket fracture found under inspection. Left hand lug cracked in position B to bolt hole (see fig. 1) and sawed off on other side (marked with cross.)

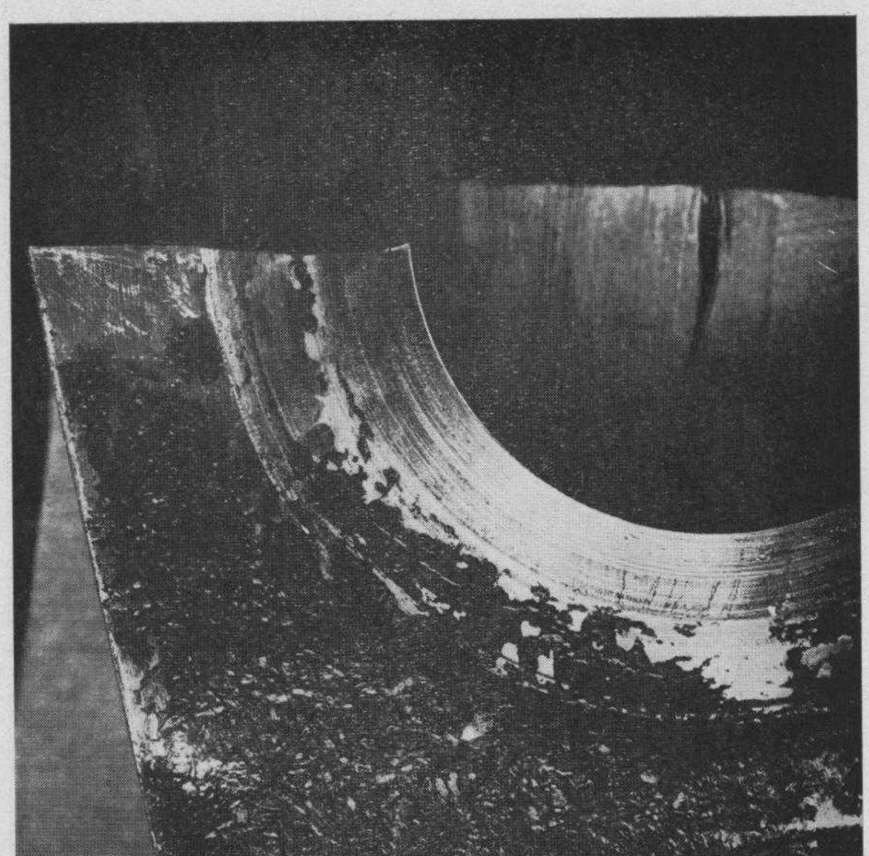

Fig. 4. Pelton bucket lug with fatigue fracture on left hand side to bolt hole (natural size). This type of bucket weighs about 190 kg.

FIG. 5. Face view of same fracture shown in Fig. 2. (Natural size) Bolt hole is on left hand boundary on photograph.

reproduced in fig. 6 for chromium steels in salt spray. Here it will be seen that by extrapolation the alternating stress corresponding to a life of 10^9 cycles/sec. is of the order of $+$ 1,200 kg/cm or roughtly 3 times the estimated nominal maximum stress. However, it is appreciated that stresses arising from vibrations have not been taken into account, and it is hoped that it will be possible to make some direct determinations of stresses on turbines in operation by means of strain gauges.

3. Proposed Remedial Measures.

As a new turbine was to be ordered for the plant where the failures cited had occurred it was decided to order the wheels cast in one piece both for the new and existing units and for two new units at another plant. The present wheel with bolted on buckets will serve as a reserve for the existing turbine, while reserve wheels cast in one piece are on order for the new units. This policy was considered safest until the stressing conditions have been experimentally investigated and the various remedial measures studied with fatigue testing machines, as this work will take some time. Even though the production of such large complex castings in high chrome steel must be regarded as difficult, it is considered that the avoidance of the delicate bolt connections and the weakening of the highly stressed root sections represent substantial advantages. Turbine manufacturers in Switzerland, France and Italy have gone over to wheels cast in one piece and it is understood that German manufacturers are following suit.

With regard to remedial measures to combat or ameliorate the damaging effects of corrosion fatigue the following are under consideration:

1) the use of inhibiting paint e.g. chromate pigment or alternatively zinc rich paint or even zinc coating

2) the use of shot peening or surface rolling to induce superficial compressive stresses

3) the use of nitrided steel which on nitriding develop superficial compressive stresses.

In any case the recognition of corrosion fatigue as a limiting factor in the design of these large pelton turbines necessarily limplies that greater attention must be paid to detailed design to avoid stress raisers and to the surface finish of the lugs.

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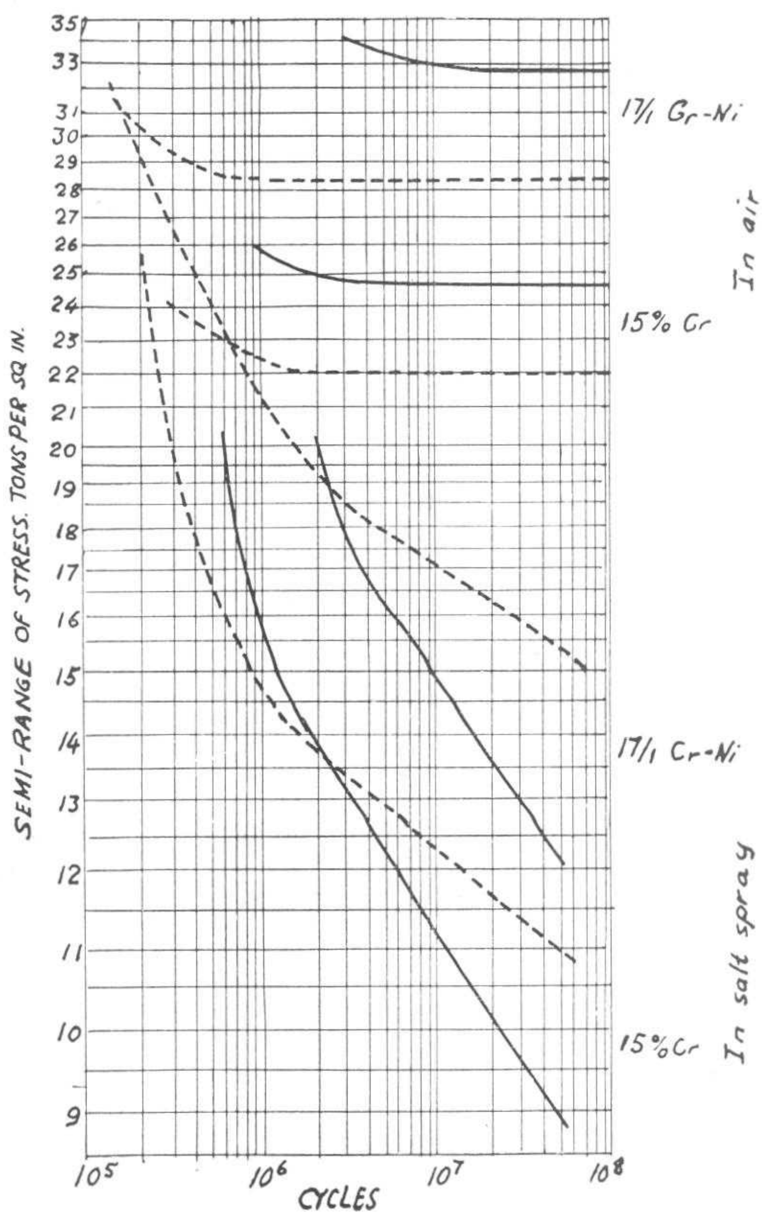

Fig. 6. Fatigue tests in air and salt spray on 15% Cr. steel and 17/1 Cr/Ni steel. Full lines: rotating bending tests: dashed lines: push-pull tests: (after Gough & Sopwith: "Comparative Corrosion Fatigue Tests employing two types of stressing action". J. Iron & Steel Inst. Vol. 127 (1933) pp 301-322).