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High cycle fatigue of welded structures: Design guidelines validated by case studies

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ABSTRACT

Experience with fatigue failures, of both welded and non-welded details, has demonstrated that the design guidelines in many fatigue codes are inadequate for fabricated equipment that requires a life exceeding 10^7 cycles. Stress ranges from strain gauge testing and finite element analysis of vibrating screens, combined with the actual life results, have been used to establish design criteria applicable to machinery operating in the giga-cycle range. Case studies from recent investigations are used to illustrate the validity of the design criteria.

1. Introduction

In the mining and minerals processing industries almost all the equipment is subjected to cyclic loading. This ranges from vibrating screens, centrifuges, feeders and mills in processing plants to excavators, shovels, trucks, long wall chocks, conveyor pulleys and load-haul-dump vehicles in open pit and underground mining.

Vibrating screens, which are used a throughout the mineral processing industry for a variety of functions including sizing, feeding and washing, operate at frequencies that result in a very high number of cycles during their required life. Typically operating at about 1×10^6 cycles per day, a life of 10^9 cycles is reached in less than 3 years. As a result they provide an ideal platform for evaluating fatigue design criteria.

Design guidelines in various international standards do not adequately address fatigue in the giga-cycle regime [1,2] and in 2001 a fatigue design approach was proposed [3], this was refined in 2006 [4], on the basis of additional field data. Recent investigations have provided further evidence that the proposed guidelines are valid, as illustrated by the two case studies described.

2. Fatigue of vibrating screens

2.1. Loads, life and environmental requirements

Screen designs are very variable in terms of size, design details, drive mechanisms and functionality. However there are elements that are common to all screen designs. Fig. 1 illustrates the typical construction of large screens. Two vertical side plates are connected at the top by a drive beam or "bridge", on which are mounted exciters with rotating eccentric masses.

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At the bottom the side plates are connected by structural steel beams, which support the screening panels, in some cases two decks of panels are used. Attached to the side plates are pedestals so that the whole screen can be mounted on springs. The various connections and joints are made using bolts, welds or swage lock bolts.

Screens are designed to vibrate at approximately 45° to the horizontal so that material moves forward along the screening deck. This motion is obtained by adjusting the eccentric masses on the exciters and results in constant amplitude oscillation at the operating frequency.

The loads and resultant cyclic stresses are almost entirely due to dynamic acceleration of the machine mass, typically around 5 g zero to peak. There is also some loading influence from the flow of material over the screen, particularly on the longitudinal and cross members supporting the screen decks. However the stress range in normal operation is typically very similar with and without material on the deck. The loading therefore approximates to a constant amplitude cyclic stress. Although there are start-up and shutdown transients, the associated stresses are typically lower than during normal operation, except at the spring support components and attachments.

Additional stresses can occur if there are natural frequencies of the structure close to the operating frequency. Individual panels, beams or parts of the screen can resonate, or the entire screen can resonate in a particular mode. However the design intent is obviously to avoid operating close to any natural frequencies of the screen. Overloading or impact with adjacent structures can also increase the stresses.

Most plant operators expect to obtain several years life at least from the processing equipment, and consequently a life in excess of 10^9 cycles is typically required. Screens are generally well protected from the corrosive mine water as well as the abrasive materials used in the plants but, because mineral processing frequently requires wet screening and the protection breaks down, data has been obtained and included for both dry and corrosive environments [4].

2.2. Vibrating screens failures

Mineral processing requirements dictate that these machines vibrate in the range of usually between 12.5 and 25 Hz, but typically 14 to 17 Hz. Depending on the utilisation these frequencies translate into a very high number of cycles in a relatively short time, Table 1. For example a vibrating screen operating at 16.5 Hz could exceed 1×10^7 cycles in only 200 h (less than 14 days) and 10^9 cycles in approximately 3 years. Consequently fatigue cracking is a common mode of failure, Fig. 2.

2.3. Fatigue design standards

Fatigue failures on vibrating screens have for many years challenged the fatigue limit adopted in most international standards for fatigue design [1–4]. For example, fatigue design codes such as BS 7608-1993 "Fatigue Design and Assessment of Steel Structures" [5], AS 4100-1990 "Steel Structures" [6], ANSI/AWS D1.1-94 "Structural Welding Code – Steel" [7] and BS EN 1993-1-9:2005 "Eurocode 3: Design of steel structures – Part 1–9: Fatigue" [8], in general do not provide adequate guidance on the approach to adopt for very high cycle fatigue regimes. For example BS 7608 assumes that in clean air, or with corrosion protection, there is a non-propagating stress range, $S_{o,}$ corresponding to $N = 1 \times 10^7$ cycles. Similarly BS EN 1993-1-9 and AS 4100 assume a constant stress range fatigue limit, $\Delta\sigma D$, at 5×10^6 cycles [6,8]. One standard that does indicate a lower fatigue limit stress range is the American Bureau of Shipping "Fatigue Assessment of Offshore Structures" in which the S–N curves are extended to 1×10^8 cycles [9].

One of the possible reasons for this deficiency in the standards is that the time required to obtain sufficient statistically relevant data would be prohibitive, since testing machines would be committed for many months on each test sample. Consequently field experience provides practical and very useful results from which design criteria can be extracted.

There is significant evidence from failures that the fatigue limit, or non-propagating stress range, in vibrating screens is at a much lower stress range than proposed in the various international standards [4]. An endurance limit, such as S_o at 1×10^7 cycles defined in BS 7608, is definitely not appropriate for the low stress, very high cycle applications encountered in mine

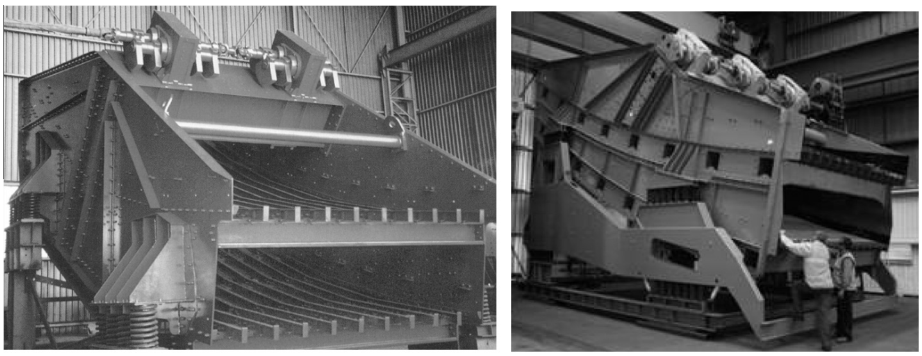

Fig. 1. Views of typical large screen structures.