FAMON

Fatigue Monitoring System

FATIGUE MONITORING SYSTEM (FAMON)

SUMMARY

In the development of a safety system for heavy lift transportation and towages known under the acronym SafePlan the fatigue monitoring system FAMON has been developed a (mobile) system as module of the marine quality kit (MQK) to determine the structural fatigue, the system records the strains in the gauges as time traces and calculates a rate of fatigue and the fatigue accumulation during the voyage

NOMENCLATURE

FAMON	Fatigue monitoring
HULLMOS	Hull monitoring system
IACS	International Association of Classification Societies
MOSES	Motion response program
MQK	Marine Quality Kit
MS	Marine Service Tool
RAO	Response Amplitude Operator
SAFEPLAN	Strain analyses and fatigue engineering a safety system
SHIPMO	Motion response program
COG	Centre of Gravity
D	Cumulative fatigue damage
GM	Distance from centre of gravity to metacentric point, metacentric height [m]
log a	Intercept of S-N curve with N-axis
m	Slope of S-N curve
n_i	Actual number of stress cycles at stress range $\Delta\sigma_i$,
N_i	Number of cycles at stress range $\Delta\sigma_i$, which will cause through thickness cracking.
$\Delta\sigma_i$	stress range [MPa]

INTRODUCTION

HMC started the joint industry project, which will result in a safety system to improve special transports with heavy transport ships.

Sensitive, heavy and bulky cargo with a low stowage factor can be damaged due to fatigue. Loads due to large heeling angels were not the cause of the damage but the accumulation of higher order motions resulted in fatigue damage.

FATIGUE MONITOR, FAMON

GENERAL

When a heavy transport object is shipped by sea, irregular cyclic loads will act on this object. In some cases these loads will cause fatigue damage. Little is known with respect to the actual level of fatigue damage sustained during a transport. In order to quantify the fatigue damage, a gauging system has been developed which can be mounted at a location on the object which is expected to be sensitive to fatigue. The system records the strains in the gauges as time traces. Moreover the system calculates a rate of fatigue and the fatigue accumulation during the voyage.

THEORETICAL BACKGROUND

When a structure is subjected to a cyclic mechanical load, cyclic stresses occur in that structure. Even when these stresses are well below the yield stress of the material used, the structure may lose integrity after a (large) number of cycles. An integrity loss shows as material cracking in areas where high stresses occur. This type of damage is called fatigue damage. Such damage can be determined by applying the S_N fatigue method.

From the stress history for the location of interest, a histogram is made of typically 20 to 30 stress ranges. The number of cycles Ni for each stress range $\Delta\sigma_i$ at which through thickness plate cracking will occurs is known from experiments. The fatigue damage D is now defined as;

$$D = \sum_{i=1}^{k} \frac{n_i}{N_i}$$

With

D cumulative fatigue damage,

n_i actual number of stress cycles at stress range $\Delta\sigma_i$,

N_i number of cycles at stress range $\Delta\sigma_i$, which will cause through thickness cracking.

The S-N curves for tubular joints are shown in Figure 1.

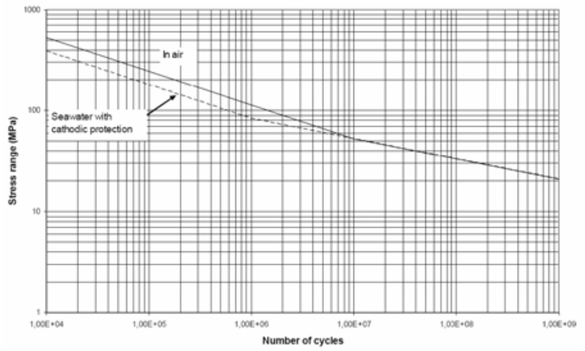

Figure 1: S-N curve, tubular joints [1]

N_i can be described by the formula below

$$\log N_i = \log \bar{a} m \log \Delta\sigma_i$$

With

N_i	predicted number of cycles to failure for stress range $\Delta\sigma$
$\log a$	intercept of S-N curve with N-axis
m	slope of S-N curve
$\Delta\sigma_{i\ i}$	stress range

or tubular joints in air, the following values are recommended [1]:

N < 107 cycles: log a = 12.164

m = 3

N > 107 cycles: log a = 15.606

m = 5

in sea water with cathodic protection

		$N < 10^7$ cycles	$N > 10^7$ cycles
tubular joints in air	$\log \bar{a}$	12.164	15.606
	m	3	5
tubular joints in seawater with cathodic protection	$\log \bar{a}$	11.764	15.606
	m	3	5
tubular joints in sea water without cathodic protection	$\log \bar{a}$	11.687	11.687
	m	3	3

Table 1: Values for log a and m, tubular joints

The stress concentration factor, SCF, is defined as the ratio of the stress in the spot with the largest stress (hot spot) and the nominal stress in the member considered. Reference is made to the recommended practice [1] when actual factors are to be determined.
The hot spot stress signals are evaluated in a rain flow.

For simple periodic loadings, such as in Figure 2, rainflow counting is unnecessary. The sequence clearly shows 10 cycles of amplitude 20 MPa. A structure's life can be estimated from a simple application of the relevant S-N curve. This compared to Figure 3 which cannot be assessed in terms of simply-described stress reversals.

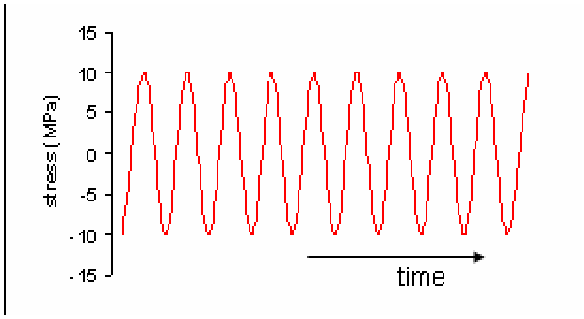

Figure 2 Uniform alternating stress history

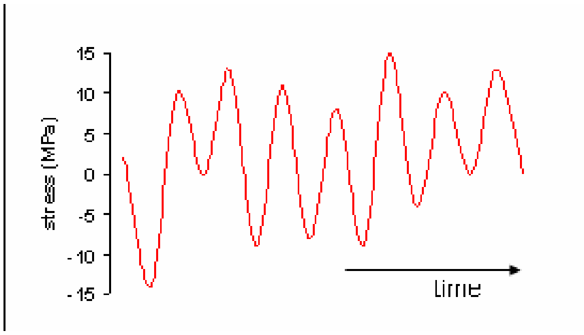

Figure 3: Spectrum loading

The algorithm

- Reduce the time history to a sequence of (tensile) peaks and (compressive) troughs.
- Imagine that the time history is a template for a rigid sheet (pagoda roof).
- Turn the sheet clockwise 90° (earliest time to the top).
- Each tensile peak is imagined as a source of water that "drips" down the pagoda.
- Count the number of half-cycles by looking for terminations in the flow occurring when either:

- It reaches the end of the time history;
- It merges with a flow that started at an earlier tensile peak; or
- It flows opposite a tensile peak of greater magnitude.

- Repeat step 5 for compressive troughs.
- Assign a magnitude to each half-cycle equal to the stress difference between its start and termination.
- Pair up half-cycles of identical magnitude (but opposite sense) to count the number of complete cycles. Typically, there are some residual half-cycles.

Example

The stress history in Figure 3 is reduced to peaks and troughs in Figure 4.
Half-cycle (A) starts at tensile peak (1) and terminates opposite a greater tensile stress, peak (2). Its amplitude is 16 MPa.
Half-cycle (B) starts at tensile peak (4) and terminates where it is interrupted by a flow from an earlier peak, (3). Its amplitude is 17 MPa.
Half-cycle (C) starts at tensile peak (5) and terminates at the end of the time history.
Similar half-cycles are calculated for compressive stresses (Figure 5) and the half cycles are then matched.

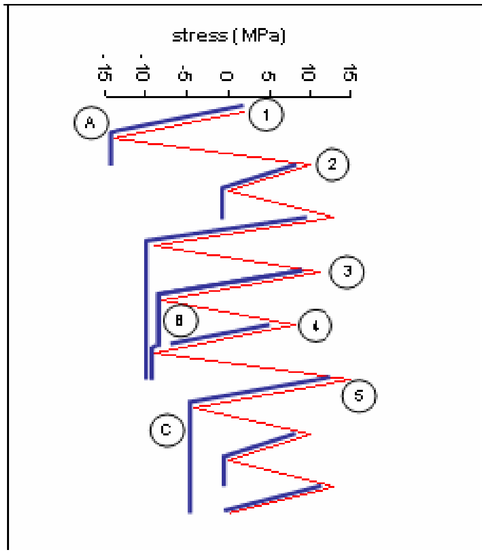

Figure 4: Rainflow analysis for tensile peaks

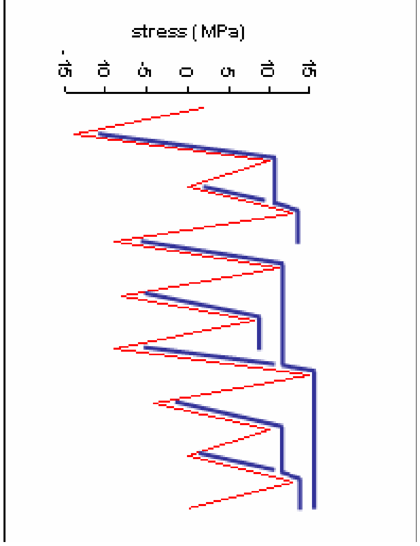

Figure 5: Rainflow analysis for compressive peaks

EQUIPMENT

The table below lists the required hardware.

name	function
strain sensors (4)	to be mounted around area where fatigue is to be monitored
sensor mounts	to be welded on the structure, facilitate mounting of sensors
data acquisition unit	must be placed near sensors because of restricted cable length
USB cable	connects data acquisition unit with lap top
no break system	protects data acquisition unit from power interrupts
lap top *(not provided by TNO)*	registers and analyses strain data

Table 2: FAMON hardware

Figure 6 shows some of the strain sensors mounted on a vertical tube.

Figure 6: strain sensors mounted on a tube

Strain sensors 1 through 4 deliver data to the data acquisition program FAMON. This program writes time traces of the stress levels measured with the sensor and depicts the cumulative damage D and the rate of damage accumulation, *dD*, as well as the damage increase over the past 24 hours.

REFERENCES

[1] Recommended Practice, Det Norske Veritas, Dnv-Rp-C203, Fatigue Design Of Offshore Steel Structures, August 2005