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# Accumulation of Fatigue Damage, Automatically Recorded and Evaluated

## Cumul du dommage en fatigue: enregistrement et analyse automatiques

## Schadensakkumulation infolge Ermüdung: automatische Aufzeichnung und Auswertung

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**SUMMARY**

This paper presents a method of recording and evaluating the accumulation of fatigue damage using an electronic device. User needs and available evaluation algorithms are discussed. The paper also includes a brief description of the hardware and software aspects. Finally, experience from field use, an example and future prospects are presented.

**RÉSUMÉ**

Cet article présente une méthode d'enregistrement et d'analyse du dommage de fatigue faisant intervenir un dispositif électronique. Les besoins de l'utilisateur ainsi que les algorithmes d'analyse à disposition y sont discutés. L'article contient également une brève présentation de quelques aspects du matériel et du logiciel. Enfin, il présente des expériences d'applications pratiques, un exemple ainsi que des développements futurs.

**ZUSAMMENFASSUNG**

Der vorliegende Artikel erläutert eine Methode zur Aufzeichnung und Auswertung der Schadensakkumulation infolge Ermüdung mit elektronischen Hilfsmitteln. Bedürfnisse der Benützer sowie zur Verfügung stehende Auswertungs-Algorithmen werden diskutiert. Ebenso ist eine kurze Beschreibung einiger Hard- und Softwareaspekte enthalten. Erfahrungen aus praktischen Anwendungen, ein Beispiel und künftige Entwicklungsmöglichkeiten werden vorgestellt.

## 1. INTRODUCTION

In using the Limit States Design Method for assessment of reliability, the structure and its components are considered to have adequate reliability if the defined most unfavourable responses, the extreme characteristics, do not exceed the limit value. These values, defined for all the reliability conditions during the life of the structure, can be grouped in carrying capacity limit states and serviceability limit states.

Special attention has to be paid to the evolution of the extreme characteristics of the structure to the loading. Especially in case of fatigue and for the evaluation of the accumulation of fatigue damage during the lifetime lack of input data may cause severe problems.

The subject of this paper is a description of a device which allows recording of the time dependent response of a structure to the loading and easy evaluation of the accumulation of fatigue damage as well as corresponding residual fatigue life.

As electronic components become more reliable and consume less power so that a device can be operated for long periods of time without maintenance, an idea has emerged to build a device which can replace costly and sensitive apparatuses like tape recorders to collect, preprocess and store information on the response history of metallic structures such as bridges, guyed masts etc. It was clear in the very beginning that such a device has to be designed to withstand various climatic and mechanical stresses. For that purpose, one-chip microcontrollers and other integrated circuits are an ideal solution.

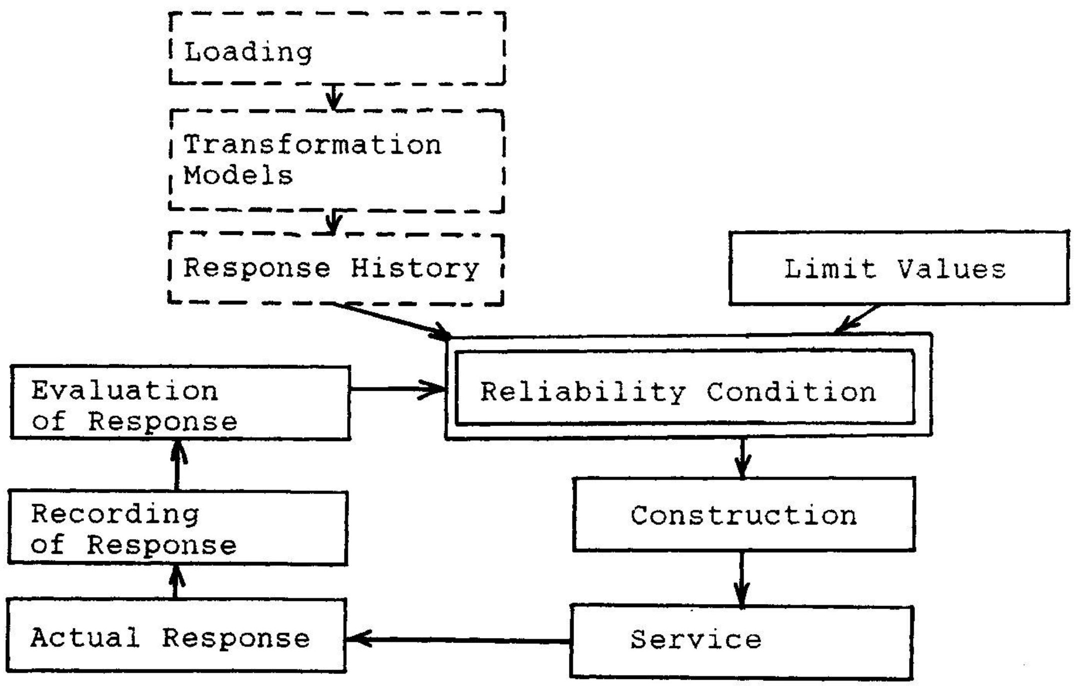


Fig. 1 Feedback Loop

## 2. USERS' DEMANDS ON THE DEVICE

In order to make the purpose of the device clear, let be mentioned the case when there are substantial uncertainties in the loading and/or the transformation model to establish the response to the loads as discussed in the feedback loop (see Fig. 1).

The structure is built and assessed subsequently based on observations in service. The response history is then evaluated and used as feedback to assess the reliability conditions. This approach is used quite frequently in the assessment of the reliability condition for fatigue [2]. It may lead to a modification of the existing structure or to an increase in the general body of knowledge, improvement of specification, etc.

The purpose of the device is the monitoring of the strain history of the metallic structure and recording the processed information in a non-volatile memory. The operator then connects the communication cable with the device and transfers the stored data into a portable computer where the information is to be evaluated.

This formulation was precised during the developing of the device, in connection with obtaining more information on the recording device currently used by the customer, while the compatibility became the main point of view, for example, analog input within the range of +- 12 V of the measured quantity was required.

There were several demands on the ease of operation and maintenance and flexibility. In the lab sample, six channels of analog input were implemented and active channels are selected by the software. Two methods of the preprocessing of the information and input hystheresis were to be selectable. For verifying the design, switches were used in the device, but in production the options will be firmware-selected so that less reliable components and cables can be eliminated.

The information is to be stored in a non-volatile memory. A CMOS memory device, backed-up by a battery, was used to satisfy the demand. The capacity of the memory can range between 2K and 16K bytes, depending on the method used and the number of channels.

Two methods of transferring the data into some evaluating device have been considered. The first possibility is to use a standard serial communication cable and to transfer the data in the desired format (RS 232) into a computer carried by the operator. An IBM PC compatible or the Sharp portable computer are two examples.

The second method is to replace the whole memory module by a fresh one and to carry the recorded module to the office where its contents can be read by a special adapter connected to a personal computer. This method eliminates the need of the computer to be carried into the field.

## 3. THE HARDWARE SOLUTION

The hardware has been designed to use Czechoslovak components where possible. An 8048 microcontroller with an external program memory has been chosen for the lab sample in order to achieve a greater debugging ability. For volume production, the 8748 or 80C48 types with a built-in program memory and a low power consumption are to be used.

The controller is clocked by a 6 MHz oscillator from which the timing information is derived to the timer and the baud rate generator. The controller's bus and ports communicate with the program storage, analog multiplexer, A/D converter, serial port, configuration switches and 8255 peripheral circuit to which the memory module is attached.

The analog input circuitry is designed to process up to six input signals within the range from -12V to +12V. The range is divided into 256 levels.

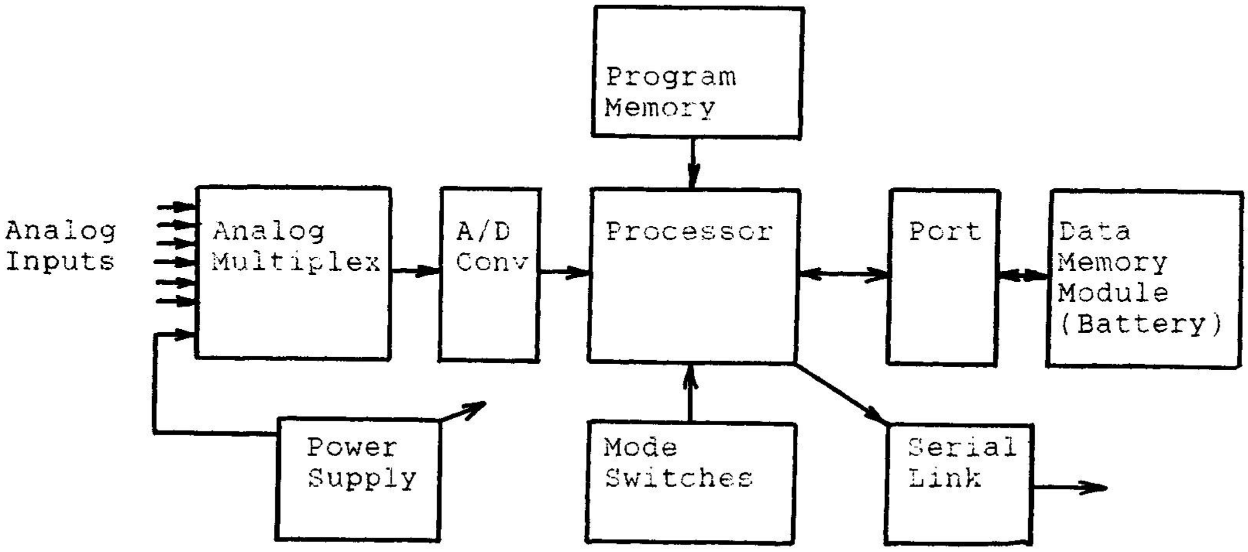


Fig.2 Block diagram of the device

The input analog multiplexer connects one of the six inputs to the A/D converter. Another analog signal can be selected by the multiplexer: the power sense signal which indicates the power failure. In that case the microcontroller disables the access to the memory.

The A/D converter converts the value of the input voltage to an 8-bit number. Though a lower resolution is required by the software, this amount of information is easy to manipulate with and is used for generating the input hystheresis. The binary number is obtained by a software controlled D/A converter and a comparator.

The asynchronous serial port is also software driven by one bit of the microcontroller's port. The TTL level signal is transformed to RS 232 levels. The transfer rate is software selectable; in the lab version 2400 bps are selected.

The configuration switches select the options of operation:

active channels, hystheresis and the preprocessing method.

An 8255 programmable peripheral interface is used to control the non-volatile memory in which the preprocessed information is stored. The memory is not directly connected to the microcontroller so that the memory module can be easily removed from the device and replaced by a fresh one. The 8255 circuit generates the addresses and control signals for the memory, the data are transferred through one of its ports. The memory cycles are controlled by the software. In the beginning of each cycle, supply voltage is checked so that in the case of a power failure the data can not be damaged. After the data are written into the memory, the checksum in the last byte is updated to ensure the data validity. If a power failure occurs, the controller notices it and resets the 8255 circuit whose ports go to the low level. Thus, the content of the memory is kept intact because the memory access is initiated by a high level on the module's control inputs.

The memory module itself consists of one or two CMOS memory circuits and CMOS logic circuits, a battery and other elements. The CMOS devices are permanently powered by a lithium battery on-board. The battery life can be estimated at five years.

During the transportation of the memory module, its inputs are kept low by resistors. In the reading adapter in the office the module is repowered by an external source and its content can be read and written into.

The power source for the device can be selected to be supplied by several voltages. In the lab sample, a simple 220 Vac 50 Hz line was chosen. Under certain conditions, when operated in a mobile structure, a 24 Vac supply may be preferred as well as a dc-dc transducer.

The device, when operated in extreme low temperature conditions like in a mountain area, may contain a thermostatic subsystem that keeps its temperature within the allowed range. The system's tolerance to high temperatures is determined by the quality of the used components and can be estimated at 100 deg C. The heat production of the device itself is very low due to the low-power CMOS technology used.

The lab sample was designed to verify the function and explore the possibilities and the users' real needs; that is the reason why its mechanical construction was not the main imperative point of view. However, the planned volume-production devices should withstand raw mechanical conditions. This aim will be achieved by using the quality printed circuit board technology with as small moving parts as possible, reliable components and a robust metallic case.

## 4. SOFTWARE

The software has been written in the microcontroller's machine language so that the demands on optimal code are fulfilled. The microcontroller's internal memory is very limited and it cannot be saved during power failure. Thus, the data memory must always keep all information needed.

The software in the program memory has three main parts. The first part is used for interfacing with the 'real world'. It manages the input signal selector, the A/D conversion, the power check and the timer.

The second part is the data preprocessing and storing into the memory. It is dependent on the employed method of analysis; the rain-flow method was used in the lab sample, the options using or omitting the mean value are selectable. This part also manages the memory depending of the number of inputs and the method used.

The third part was incorporated into the program for outputting the data via the serial line. This part gets the data from the memory, converts them to a convenient ASCII format and transmits them through the port using its own baud rate generator.

## 5. FIELD USE

The experiments verified the device's ability to collect the information from one of several analog sources, preprocess it using the rain-flow algorithm, store the data in the non-volatile memory and output them to the operator. There is a connection of the maximum number of channels, computing the requirements of the method used, the processor's speed and the input bandwidth, and also a connection between the storage demands of method used, the number of channels and the required capacity of the data memory.

The field usage confirmed the need of a reliable operation because one unreliable connector can cause a loss of worthy data.

## 6. EXAMPLE

As an example, applying the device in evaluating the lifetime of excavator for the brown coal surface mining may be mentioned. The stress in the evaluated location was measured in a selected operating mode in the coarse of approximately one month. The obtained representative spectrum of the response is shown in Fig. 3. This information was further used in estimating the life to initiation of fatigue crack.

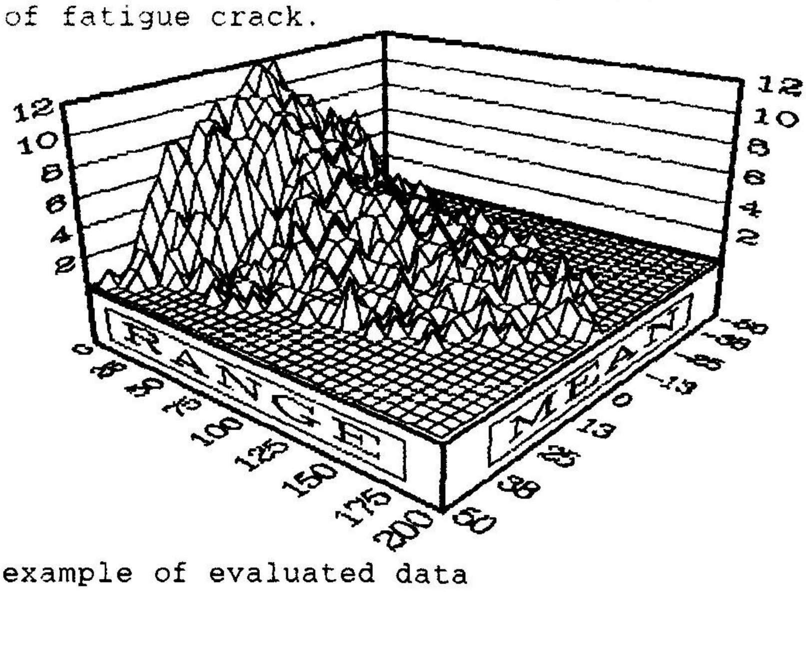


Fig. 3 An example of evaluated data

## 7. CONCLUSION AND FUTURE PROSPECTS

This paper described a method of measuring, processing and storing the data on fatigue damage of the structure. A microprocessor-based electronic device doing that job was presented. We hope that in mass use, thanks to its low price, it may be mounted permanently on critical parts of the structure and monitor its history so that the residual life may be determined as well as theoretical knowledge may be acquired.

The device should collect and evaluate the data concerning the level of the fatigue damage in real time and accumulate it for long periods of time.

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