A STATISTICAL MEASURING INSTRUMENT FOR HISTOGRAMS

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Machines and structures working under nonstationary operating conditions — such as vehicles, cranes and other transporting machines, agricultural and many other sorts of machinery — encounter in service continuously but irregularly varying loads. The maxima and minima of the forces acting on them change randomly in magnitude and sequence. It is well known that the life of such machines will be considerably shortened by the so caused fatigue, unless the stresses are very small.

This presents increasing difficulties for the reduction of the size and weight of these machines, which is equally important for reasons of serviceability as well as economy of construction and operation. High tolerated stresses and an undetermined life form a contradiction which can only be solved if we do not expect the service life of our machines to be almost unlimited. In the course of technical development all machines anyhow become obsolete and must be sorted out more and more quickly for technical-economical reasons. Thus we may expose our structures to considerably greater stresses than the "fatigue limit" connected with an unlimited service life, if these do not reduce this life below the desired endurance. An up-to-date strength-calculation should therefore be made for a predetermined limited service life.

Since the phenomenon of fatigue is very intricate and not yet known adequately, the determination of the endurance or service life of machines and structures is today practically impossible without fatigue tests [1]. These tests must be conducted simulating the expected service conditions as precisely as possible. For this pupose therefore only program-controlled fatigue-testing machines are suitable, such as for instance the SCHENCK pulsator with a capacity of 12 ± 8 megaponds, which is put into service in the spring of 1964 at our Department of the Polytechnical University in Budapest. On this machine the magnitude of the fatigue forces is controlled by a punched tape according to a program derived from a survey of service loadings. To set up this program, or even for the consideration of service conditions only, however, it is indispensable to know the acting forces thoroughly which may be expected to arise in the structures in the course of their desired service life.

The factors determining these forces — such as the routes and the quality of the roads for vehicles, quantity and distribution of passengers and cargo, travelling speed, accelerations acting on the structures or on their components, etc. — may occur more or less independently of each other, and vary randomly in magnitude. An appropriate treatment of such randomly varying phenomena can only be achieved by means of mathematical statistics. In contrast to the static strength-calculation of a stationary structure, here we cannot be content with the knowledge of the maximum values of the loads, but must survey the load-spectrum too, i.e. the frequency-distribution curve of the magnitude of expected loads.

Instead of a continuous curve in practice only a histogram may be obtained, in which the measured loads are sorted according to magnitude into distinct classes. If one wishes to take into account with the spectrum the character of the random fluctuations properly, it is for statistical reasons necessary to measure and evaluate a very great amount of data. The evaluation of a frequency distribution recorded graphically, e.g. by oscillogram, is a very cumbersome and time-absorbing task. Evaluation by counting requires — as experience shows — about a hundredfold the measuring time [2]. This great amount of labour and time to be spent for evaluation naturally restricts the quantity of data to be analysed, and so the reliability of the statistical results.

Almost as important is the requirement, that the results of the measurements should be available as quickly as possible. Considering the fast growing speed of technical development today it does not seem unreasonable to visualize that results counted traditionally may already be regarded as almost obsolete at the time their evaluation would be completed.

It is thus greatly desirable to be able to evaluate the longest possible observation — a very great amount of data — in the shortest time possible.

The only effective way to reduce the labour of evaluation is automation. Electronics enables us to construct instruments which, eliminating graphical recording, directly indicate the results of counting. Such an instrument is the Histometer (Hungarian pat. No. 150 620).

Operating principle of the Histometer

Several types of statistical evaluating instruments are made all over the world to-day. Their common feature is that they transform the quantities to be measured first into proportional small electric tensions. These signals are then amplified, classified according to their magnitude, and finally summed up in every class separately.

The counting principle of each instrument is different. The "VGH-recorder" of the NASA (USA) counts and classifies the extreme values of oscillations encountered between two crossings of the mean value. The "Strain-Range Counter" developed by Vickers counts the mean values of every range-pair of larger amplitude. The "Fatiguemeter" of the Royal Aircraft Establishment (RAE) (England) counts the crossings of the sorting levels by growing signals, below and above the mean value. The counters of the West-German firm Hottinger also count level-crossings. The earlier type did this by chopping the signal regularly at fairly long intervals, but this method has been given up later on, because serious miscounting may result, if the frequency of the

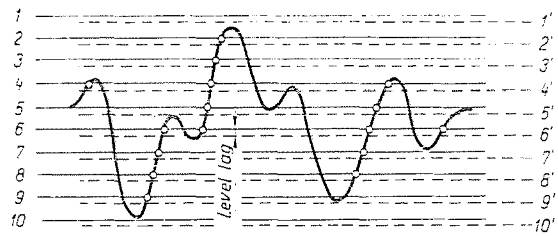

Fig. 1. Counting of level-crossings

signal-waves and choppings is comparable, or, the magnitude of the signal is changing slower than a critical value. Other instruments integrate the area below the signal curve or count the classified magnitude of the peaks of every oscillation of the variable.

A full information about a randomly oscillating variable can only be obtained by the combination of two different counting methods [3]. Still we can get sufficient approximation by taking either of them, if the mean value of the single oscillations does not differ considerably from the medium level of the total curve. Obviously this is mostly the case, as the practical results obtained by the several methods mentioned differ surprisingly little [4, 5, 6].

The Histometer also operates on the principle of level-crossing by growing signals, but is independent of mean values of the variable or variations of the static load. To suppress small disturbing oscillations of higher order, the signal is required to fall by a given value below the crossed level before it can actuate the counter a second time (Fig. 1).

To obtain the load spectrum of machines and structures the measuring of occurring stresses by strain-gauges seems the most suitable procedure. Describing the fully transistorized second version of the Histometer this application will be taken as an example. This device is, of course, not only suitable for the analysis of oscillating mechanical stresses, but of other physical quantities also which may be transformed into electrical signals, even for the evaluation of oscillograms registered earlier by other instruments.

Electrical structure of the Histometer

The latest version of the device is placed into two boxes (Fig. 2), one of them containing the amplifier, the other the analyser equipment. Electrical supply on vehicles is taken from the board network of 24 volts d.c., or else from a suitable battery.

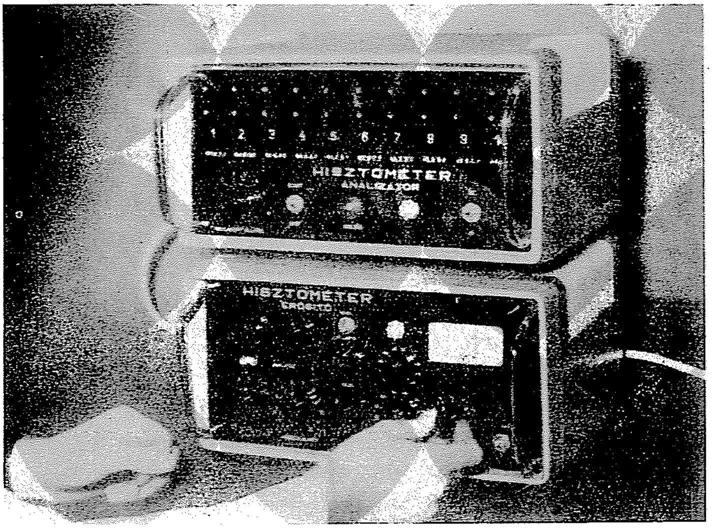

Fig. 2. The Histometer in use

a) *Amplifier equipment (Fig. 3)*

The local mechanical strains created by the acting loads — in an elastic medium known to be proportional to the stresses — must first be transformed into proportional electric voltages by means of suitable detectors, e.g. strain-gauges. A measuring gauge and a gauge compensating eventual fluctuations of temperature are applied at a chosen point of the component to be examined, and connected into an ordinary Wheatstone bridge. Balancing the bridge in its basic position, the voltage appearing under load on its output terminals is proportional to the mechanical strain or stress to be observed. If the bridge supply is by a.c., the phase angle of the current gives the direction of the stress too.

The block scheme of the electric function of the amplifier is shown in Fig. 4. The system utilizes the advantages of carrier-frequency measurement. A d.c.-system might be disturbed by occasional thermal and contact potentials, and the construction of a d.c.-amplifier with appropriate zero-point stability would be very complicated and inadequately expensive.

An oscillator, whose operating frequency is 4 kHz $\pm$ 6%, controls the bridge-amplifier and provides a constant load for the oscillator which is independent of the nominal resistance of the actual strain-gauge. This amplifier supplies not only the Wheatstone bridge, but also the separator stage affording the reference signal for the phase-sensitive demodulator.

The output signal of the Wheatstone bridge passes to the input terminals of a d.c.-connected two-stage low-noise amplifier. This pre-amplifier is followed up by a bandspread-circuit with constant output resistance regulating the measuring limits of the whole instrument. This circuit works by controlling

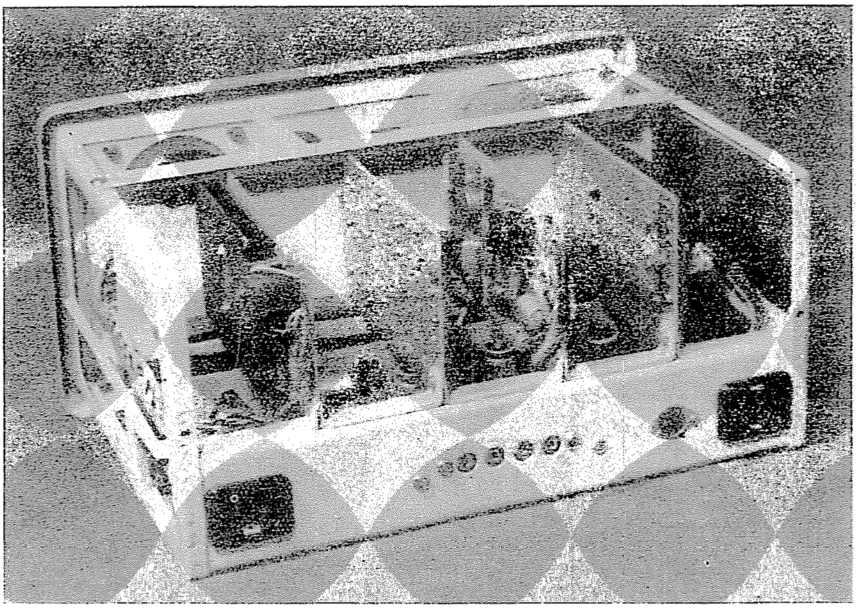

Fig. 3. Amplifier equipment

the amplification of the system gradually in stages of 2 dB, and between these stages by a continuous fine amplification control. Thus it is possible to take advantage of the total band-width-capacity of the final amplifier, and also to adjust the amplification to strain-gauges with different gauge-factors.

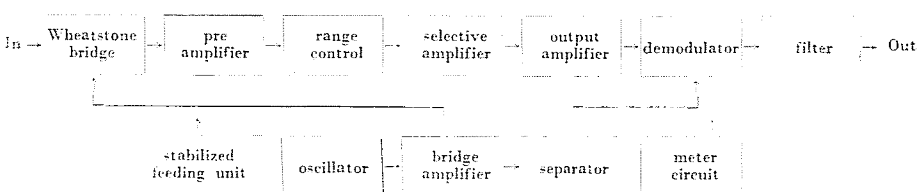

Fig. 4. Block scheme of the amplifier equipment

As selective amplifier serves a two-stage, directly coupled, twin-T-circuit stabilized by a great negative feedback, which ensures the powerful damping of eventual disturbing harmonic noises. The full band-width of the amplifier is of the order of 1 kHz and is, therefore, insensitive to small frequency shifts of the oscillator and makes so an accurate adjustment unnecessary.

The two-stage output-amplifier comprises a pair of direct-coupled transistors with negative feedback. The secondary coil of its transformer provides the supply for the phase-sensitive demodulator.

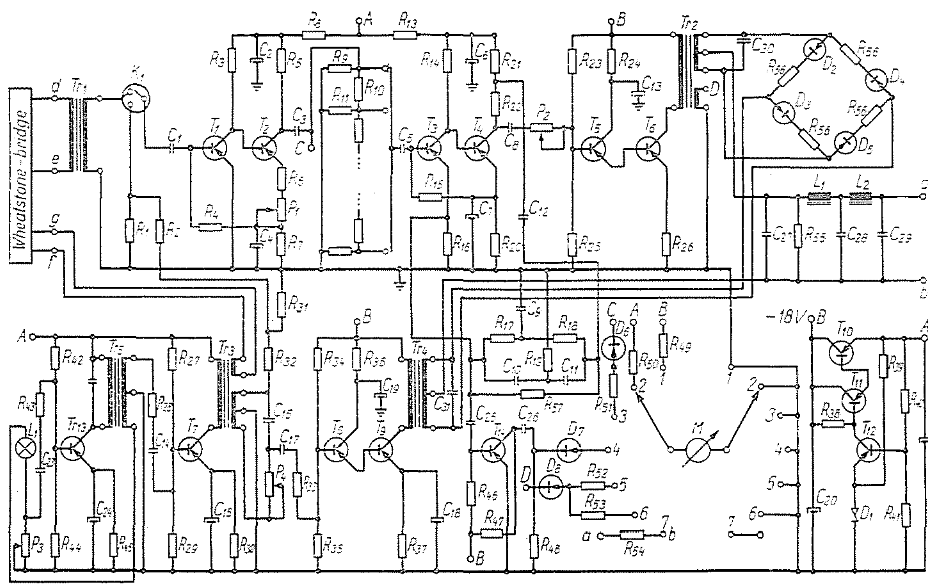

Fig. 5. Connection diagram of the amplifier equipment

To the output terminals of the demodulator the low-pass LC filter with a pass range up to 150 Hz is connected which at the operating frequency of the oscillator has a damping of at least 80 dB.

On the output terminals (a, b) of the amplification system appears a current of 0 to 150 Hz frequency whose voltage is proportional to the measured quantity. This signal is transmitted to the input of the classifying circuit of the analyser equipment.

A meter within the amplifier set makes it possible to check the supply voltages and the zero setting of the Wheatstone bridge, as well as calibrating the amplification of the total set.

Fig. 5 is the connection diagram of the amplifier equipment.

In place of the Wheatstone bridge, of course, there may be any other signal-converter connected to the terminals d, e, f, g of the amplifier. Instead of mechanical strains various other random physical quantities (velocities, accelerations, etc.) can so be measured and analysed statistically. To the terminals *a*, *b* of the amplifier a recording equipment (direct-recorder, oscilloscope, oscillograph, etc.) may be fitted too and thus, if required, the results may be laid down in a diagram also.

Table 1

Technical data of the amplifier equipment

Input resistance between terminals *d-e*	$R_{in} \geqq 3$ kOhms
Drive voltage between terminals *d-e* at maximum sensitivity	$U_{in} = 20\ \mu V_{eff}$ (carrier frequency)
Output voltage between terminals *f-g*	$U_{out} = 2.5\ V_{eff}$ (carrier frequency)
Loading resistance between terminals *f-g*	$R_{load\,max} \geqq 200$ Ohms
Amplification	$A \geq 115$ dB
Carrier frequency	$\omega_c = 4$ kHz $\pm$ 6%
Frequency range	$\omega = 0 \ldots 150$ Hz $\pm$ 2 dB
Output resistance	$R_{out} = 500$ Ohm
The Wheatstone bridge can be balanced for amplitude and phase by an internal zero circuit.	
Internal calibrating signal	$U_{cal} = 20\ \mu V$
Amplification control (gradual)	22 dB, in stages of 2 dB
Amplification control (continuous)	2.5 dB
The Wheatstone bridge is calibrated for	$\sigma = 50 \ldots 630$ kp/cm² mechanical stress per class
Neutral (zero) point stability (drift) related to input better than	0.5 μV/h
Noise related to input (in the range of 0...150 Hz)	$U_z \leqq 0.1\ \mu V$
Working temperature range	0...+ 45° C
Supply	−18 volts from battery
Power consumption	$I < 1$ Amp.
Weight	7 kgs
Size in mm-s	250 × 250 × 400
Design	transistorized, with printed wiring

b) *Analyser equipment (Fig. 6)*

The voltage appearing on the output terminals *a*, *b* of the amplifier and proportional to the measured quantity becomes classified and is distributed into 10 channels. Each channel comprises one amplitude-analyser and one counter unit, and covers 1/9th of the total voltage range to be analysed, the voltage-differences between the comparing levels of all channels being equal. The block scheme of the electric function of the analyser is shown in Fig. 7.

Influenced by the signals arriving at its input, the respective Schmitt-circuit is triggered at its critical voltage level from its first stable state into the second. Thus a voltage jump is produced at the output of the circuit and this impulse actuates the counter unit. With a decreasing signal (which is not counted) the circuit is triggered back into its first position at a slightly lower level. The two triggering levels being unequal there is some play between

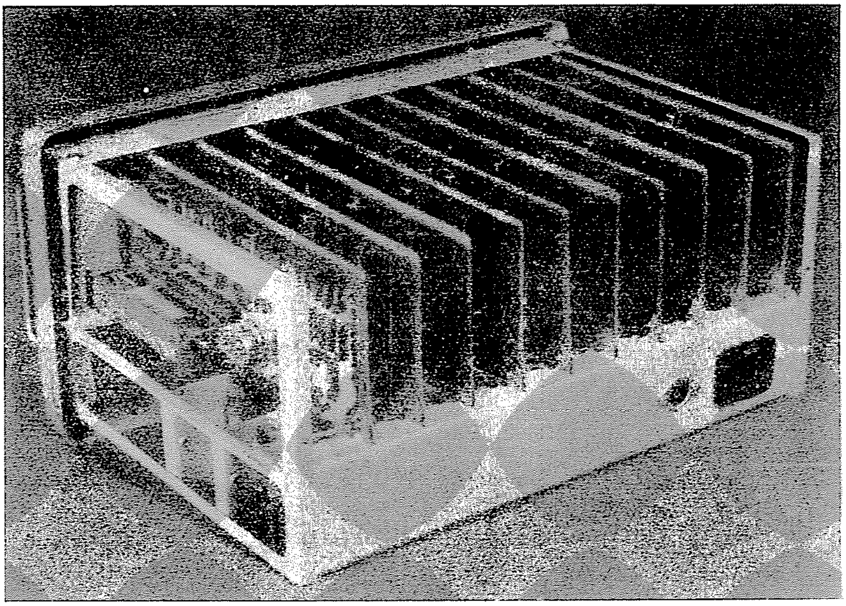

Fig. 6. Analyser equipment

them, called here "level lag". As long as the decreasing signal has not passed this lag a new growing signal cannot be counted in this channel.

The frequency of the impulses equalized by the Schmitt-circuit becomes successively halved by two bistable multi-vibrator (flip-flop) circuits, so that it is every fourth impulse which operates the counter through an impulse-amplifier. The counting-frequency range of the analyser is thus quadrupled and spans from 0 to 160 Hz, though the capacity of the counter itself ranges only from 0 to 40 Hz. Should a greater working range be needed the number of the bistable circuits can be increased.

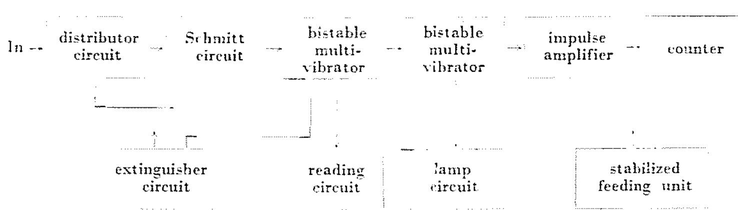

Fig. 7. Block-scheme of the analyser equipment

The number of impulses read off from the counters must, of course, also be multiplied by 4. In order to be able to take into account the impulses

Table 2

Technical data of the analyser equipment

Total signal range	U_{max} = 8 Volts
Level difference of the single channels	U = 0.8 ± 0.1 Volts

The levels of all channels can be shifted simultaneously in 5 stages of 0.9 V each

Maximum counting frequency	n = 150 Hz
Numbers capacity	$4 \times 10^5 + 3$ impulses
Reading off	by electro-mechanical counters
Input resistance	R_{in} = 1 kOhm
Working temperature range	0...+ 45° C
Level lag	cca. 0.2 of channel range
Supply	−18 Volts and +6 Volts from battery
Power consumption	≤ 2 Amperes (−18 Volts) and 0.05 Amperes (+6 Volts)
Weight	7.5 kgs
Size im mm-s	250 × 250 × 400
Design	transistorized, with printed wiring

left out by the counters the bistable circuits are provided with signalling lamps counting the intermediate impulses from 1 to 3.

Fig. 8 shows the circuit connection-diagram of the analyser equipment. This equipment may also be used as a self-contained unit if the voltage of the

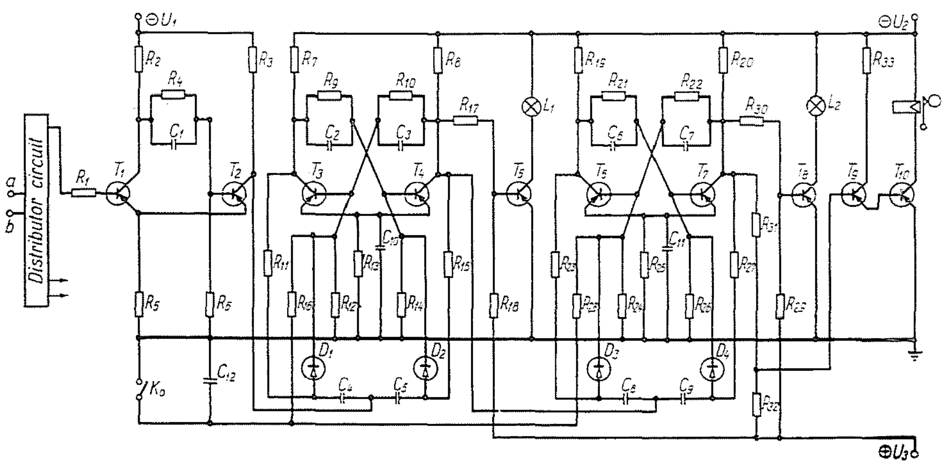

Fig. 8. Connection diagram of the analysing equipment

current to be analysed is large enough not to need amplification. This voltage may then, after reduction to max. 8 Volts, be directly connected to the input terminals *a*, *b*.

Mechanical structure of the Histometer

Structure and form of the instrument were determined by the requirements of portability and for use on vehicles on scheduled service. Low weight, small size, slight current-consumption, independency of mains, effective protection against external influences and vibration-proof construction were the chief objectives. Economical production as well as simple handling and repair were also kept in view.

All elements of the two stressed-skin boxes containing the device are from 0.8 mm steel plate. Profiles made of thin sheet unite low weight and great stiffness. Steel chosen as basic material enables the application of spot-welding and functions also as electrical and magnetical screening. For ventilation and cooling at the bottom of the oxes and on the upper edges of their sides apertures are opened. The upper apertures are covered by expanded sheet which has an open surface of 75% of its gross area and also provides a certain protection against dust. Air flow is ensured by chimney-effect. The two boxes have the same size and may be placed above each other, the legs

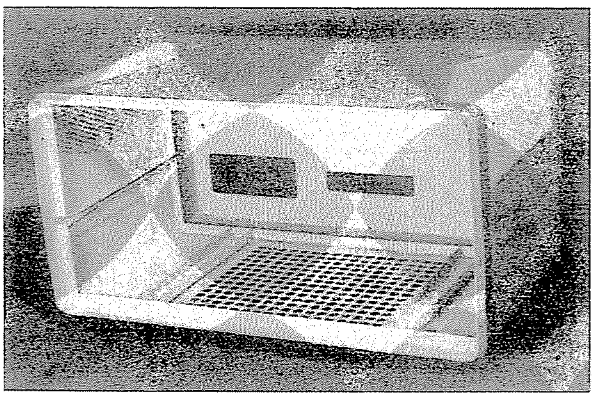

Fig. 9. Skin-structure box

of the upper box standing in dents on the top of the lower one. This prevents slipping of the upper box by any small movement.

Outside on each box there are no more than two screws fastening the drawers. Unscrewing can be done with a coin, and pulling out the drawer makes all electric units readily accessible. The drawer can only be pulled out when the connectors are uncoupled and the instrument is dead. Anyhow, the maximum voltage to be met within is 24 volts, which may be even touched free from any danger.

The drawers are built on the same principles as the boxes (Fig. 9). Only a few sorts of materials were used, and the structure is light-weight and rigid. Welded joints provide a perfect body-contact. The pulled-out drawers rest on legs and can be placed on a table even on their side without damage to the mounting panels. All terminals are situated on the rear, all controls on the front plate. The controlling buttons are arranged in logical order and protected against injury by handles attached to the front plate. By these handles the drawer may be pulled out, lifted and transported with and without box.

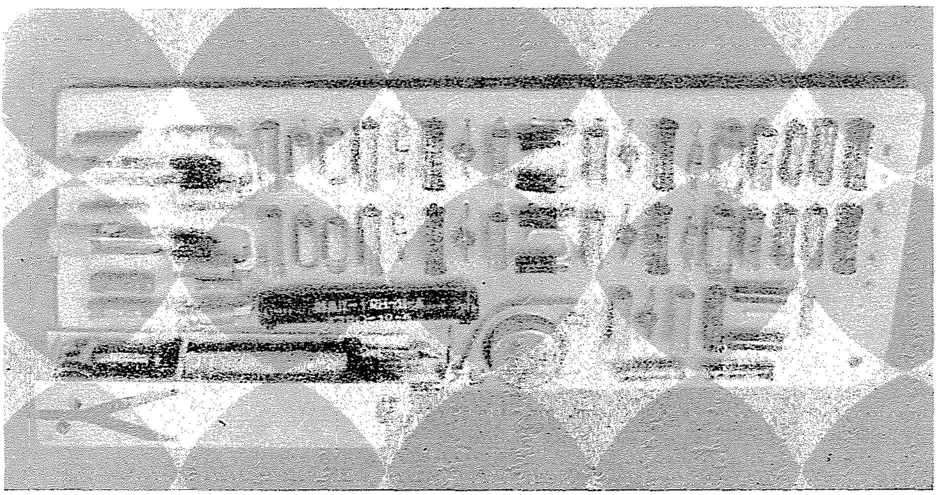

Fig. 10. Counting unit

All electric circuits are printed on panels and fully transistorized (Fig. 10), showing thus compactness, small consumption and low weight. Printing eliminates wiring error, it is nice, easy to repair and suitable for very economical production-in-series.

Commercially available materials were used as far as possible. The only exceptions are a few transistors in the most delicate components (e.g. pre-amplifier, Schmitt-circuits).

The printed panels are arranged in parallel standing on their edges, thus saving volume and giving freedom for the air to flow between them. Heavier loaded transistors are fitted with radiator fins. Under service conditions no overheating is to be expected.

After unfastening of one fixing rod all electric panels in the box may be swung out separately (Fig. 11). Every component is then easily accessible and it is not necessary to severe any internal connections for repair. Possible contact troubles are thus avoided. The range switches selfclean their contacting surfaces at every turn.

As the measurements take place mostly on vehicles, the device is specially built against shocks. Every part is properly fastened and secured. The lightness and rigidity of the structure reduces mass forces and vibrations as far as possible.

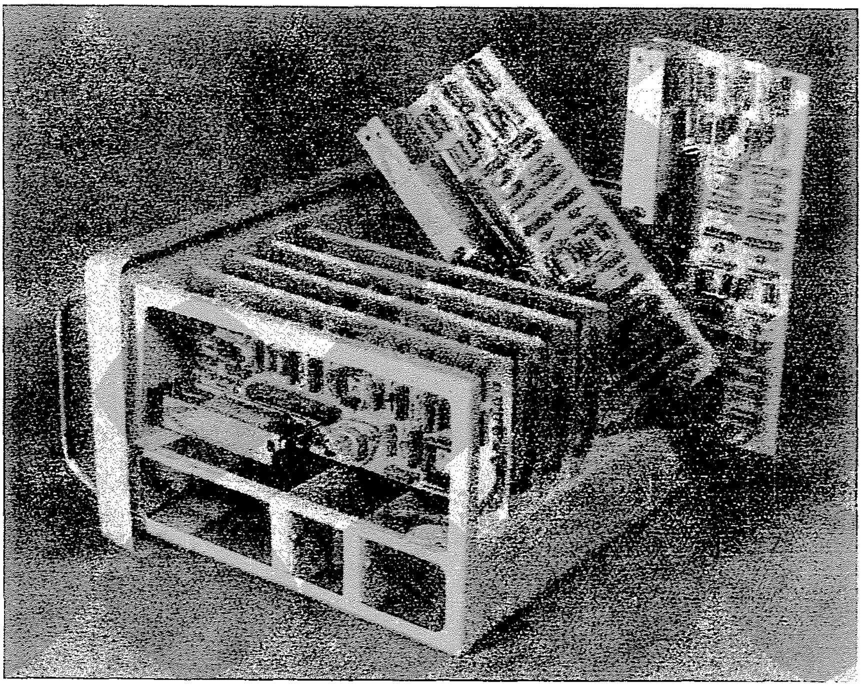

Fig. 11. Unit-panels lifted for access

Interference of electric circuits is eliminated where necessary by internal screening plates.

All metal parts are protected against corrosion by galvanic coating and painting. Outside coating is hard enough to provide protection against small damages.

With the Histometer it is possible to make both static and dynamic measurements. A great advantage of the device is that the zero-level can be shifted to any arbitrary position, that symmetrical fluctuations may thus also be analysed. Sensitivity can be varied too, so that irrespective of the magnitude of the signal the capacity of the Histometer can be fully utilized in any case. Thus with every measurement we get at least 8 to 10 points of the histogram, which is sufficient to plot the curve with proper accuracy (Fig. 12).

These features enable the Histometer to perform widely varied measuring programs. Thus we may obtain a detailed statistical analysis of service loadings, based on a practically unlimited number of data, almost immediately after finishing the test run. Readings of the same reliability may be taken without interruption of the run at every desired point of the test. In this way we may easily and within the shortest time obtain all the necessary data

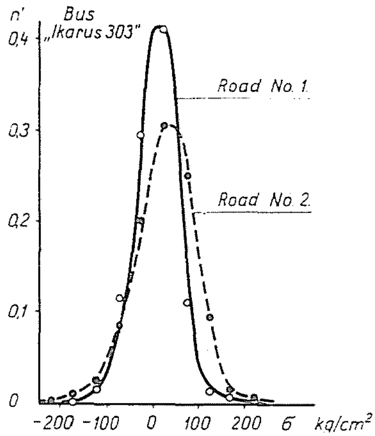

Fig. 12. Test results

of the construction of a really service-like program for fatigue tests with structural parts of vehicles or other machinery on a suitable program-controlled fatigue machine, or for the simulation of other service conditions.

Summary

The study of structural fatigue and other randomly varying phenomena requires the statistical analysis of physical quantities. A histogram based on a sufficiently vast amount of data can be obtained economically only by automatic devices. The Histometer amplifies an electric signal proportionate to the quantity to be examined, classifies it according to the crossing of predetermined levels and counts the level-crossings automatically. It is composed of an amplifier and an analyser set. Both may also be used separately. Their electrical and mechanical structure is described in detail. Small size and weight, adaptability and ease of handling make the Histometer suitable even for measurements on vehicles in scheduled traffic, i.e. under entirely unaffected service conditions.

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