of inclusions on stress concentration of boundaries of notches are shown in Figs. 11, 12, 13 and 14. In these figures abscissa is $\sigma_m/(P/2b'h)$, ordinate is $\lambda=d/b$. It is seen that for duralumin inclusions the values of $\sigma_m/(P/2b'h)$ are certain constants at the same values of $c=b-(d-r)$.

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Fig. 14 The influence of sizes of inclusions on stress concentration on the boundaries of notches for holes

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New Resonance Type Fatigue Testing Machine*

By Minoru KAWAMOTO**, Tsuneshichi TANAKA***,
and Yukihiro IBUKI****

A new direct stress fatigue testing machine which operates in a perfectly resonant condition under a new principle is devised and constructed. In this machine a repeated load is applied to a specimen by the inertia force of a mass forcibly vibrated by a crank and link mechanism just in a resonant condition. The amplitude of the vibration can be adjusted mechanically from zero to an arbitrary magnitude in operating condition without stopping the machine. So the starting is easy and the amplitude is kept strictly constant without any automatic control apparatus.

The machine is proved to be satisfactory in operation. Some experiments are made on smooth specimens, notched specimens, and others.

1. Introduction

Fatigue testing machines which have been developed and employed to this day can be classified into three fundamental types according to the relation between the loading frequency and the resonance frequency of the main vibrating system of the machine: non-resonance type, semi-reso-

nance type and resonance type. The loading frequency of a non-resonance type machine is far less than the resonance frequency, so the inertia force of its moving parts is fully disregarded, and accordingly a load on the specimen is purely static and, therefore, accurate. In this type, however, since the load is not magnified by resonance, the whole structure should have a large strength and rigidity, and therefore it becomes massive. In a semi-resonance type machine, the operating frequency is usually a little less than the resonance frequency, and in a resonance type, this frequency fully coincides with the resonance one. Although a

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** Professor, Faculty of Engineering, Kyoto University, Sakyo-ku, Kyoto.

*** Assistant Professor, School of Science and Engineering, Ritsumeikan University.

**** Assistant, Faculty of Engineering, Kyoto University.

large magnification of the load is easily obtained in these types of machine, a fine speed regulator or load controller is generally required, since the magnification factor is sharply affected by the operating speed.

Cox and Owen developed a machine which was operated at a resonance point⁽¹⁾. They used a coil spring in series to the specimen to lower the resonance frequency of the main vibrating system, and also used a crank mechanism to drive it. As this crank mechanism had a function only to determine the amplitude of vibration, a little power was needed to drive it and a fine control system was not necessary. However, one difficulty was how to start the machine and accelerate the vibration up to the resonance speed. To avoid this difficulty, they used another mechanism to start the machine, then switched to proper operation by means of a slipping clutch.

Recently, the authors have also developed a resonance type machine using a simple mechanism to excite the machine by which the load amplitude was kept accurately constant, and the difficulty of starting was overcome with success.

2. Principle and structure of the machine

The principle of the machine is shown in Fig.1 schematically. The load to specimen 1 is produced as an inertia force by the vibration of the mass-spring system 2 and 3. The system is driven by means of the crank mechanism 5, 6, 7, 8 and 9 at the resonance speed. The amplitude of vibration is arbitrarily determined by adjusting the position of hinge block 6, which has a slide metal 4 placed in the slot of vertical lever 5.

Fig. 1 Principle of the machine

Fig. 2 Photograph of the machine

This block is moved by turning the screw 10 with handle 11. Before the machine is started, hinge block 6 is set to the highest position, and is kept at that position until the frequency of the system becomes equal to the resonance one. After that, the hinge block is lowered to an arbitrary position to give a finite amplitude to the mass-spring system. As a matter of fact, the hinge block is so designed as to come up to the same level with the specimen, so that the starting load can be reduced to almost zero in the actual machine. After the resonance point is reached, only a fraction of driving force is necessary to keep the resonance vibration for any position of the hinge block, and the amplitude is completely constrained to be constant. Thus, the small and simple driving parts are enough to generate a fairly large and stable load amplitude in the main system, including the specimen under the resonance condition.

The machine is shown in Figs.2 and 3. The horizontal type is adopted to secure an enough rigidity. Specimen 1 is fixed by tightening nuts 9 to the loop dynamometer 3 at one end and to the coil springs 11 and 12 at the other end. The coil spring 12 located inside the coil spring 10 composes the vibration system with the main mass 14 and the adjustable mass 13. Mass 14 is connected with vertical lever 24 and connecting rod 23. Slide metal 20 placed inside the slot of vertical lever 22 is pinned to the movable fork type hinge block 19, and the vertical lever oscillates together with the slide metal around the hinge pin and excites the main system. The vertical position of the block is adjusted by turning the screw 17 with handle 21. The static preload is applied to the specimen by the coil spring 10, which is pulled by turning the handle 15 through the pull rods

Fig. 3 Structure of the machine

18. A decrease of preload which may occur during the test due to the deformation of specimen is adjusted by means of a fine movement of main spindle 4. The spindle is supported by stock 5 and driven by motor 7 or by handle 6 through a screw and reduction gears. A special device is put on that part to avoid a clearance of driving screw. Therefore, the adjustment of preload can be done without stopping the machine whenever the specimen deforms. This mechanism is available particularly for a test at elevated temperatures. Switch-board 11 is placed to detect the decrease of preload and the fracture of the specimen.

Based on the calculation, the variation of the load amplitude is less than 0.6% when the driving frequency fluctuates in the range of $\pm 3\%$ around the resonance frequency.

The machine is specified as follows:

Maximum repeating load..... ± 10 tons
Maximum static load 20 tons
Maximum distance between grips ...550 mm
Available height of grips from bed...400 mm
Normal operating speed2 500 rpm

3. Several fatigue test results

1) **Fatigue strength of plain, notched and threaded specimens** Plain, notched and threaded specimens made from the same medium carbon steel bars of diameter 44 mm were tested under a completely reversed repeating load. The chemical

composition and the mechanical properties of the material are shown in Tables 1 and 2, respectively. Details of specimens are shown in Fig. 4. The notch form of specimen (b) is copied from a thread of specimen (c). The latter has four perfect threads at the middle part.

Fatigue test results are plotted in Fig. 5. The strength of the threaded specimen is larger than that of the notched one due to the reduction of damaging effect of notches caused by their interference. Three plots with half shadowed circle are from the results of the check test, using a plain specimen of the same diameter as specimen (a), which were obtained by the 60 ton pulsator machine of Losenhausen type.

Fig. 6 indicates the temperature increase of specimens tested at three different stress levels.

Table 1 Chemical composition % of the material

Symbol	C	Si	Mn	P	S
0.34% C steel	0.34	0.24	0.48	0.016	0.028

Table 2 Mechanical properties of the material

Symbol	Yield point kg/mm ²	Tensile strength kg/mm ²	Actual breaking stress kg/mm ²	Elongation %	Reduction of area %	Hardness Shore
0.34% C steel	31.8	55.3	89.9	22.6	48.5	21.0

Fig. 4 Specimens

Fig. 5 Fatigue test results

Fig. 6 Temperature increase of the specimen

Table 3 Chemical composition % of the material

Symbol	C	Si	Mn	P	S	Cu	Cr	Al
A	0.26	0.35	0.80	0.019	0.020	0.17	0.05	—
B	0.29	0.28	0.46	0.015	0.029	0.09	—	0.012

Fig. 7 Fatigue test results of the deformed bars (minimum stress 2 kg/mm²)

Thus, for a comparatively large plain specimen, temperature increases extraordinarily, when a specimen is under a high repeating stress. This temperature increase fully depends on the load frequency when specimens of the same size are used. And, when this increase attains several hundred degrees, the fatigue strength necessarily receives a large influence. That is one of the reasons why the normal speed of the machine is suppressed to 2500 rpm, which is relatively small in comparison with other resonance type machines.

2) Fatigue strength of deformed steel bars

Two sorts of deformed steel bar used for reinforced concrete were tested under a pulsating load. These bars have the same nominal mean diameter of 15.9 mm, but are different in their surface designs and denoted here as bars (A) and (B). Specimens cut from these bars were finished to the final length 200 mm after bulging both ends by forging and then threading there. The chemical compositions and the mechanical properties are shown in Tables 3 and 4, respectively.

The test results are plotted in Figs. 7 and 8. Fig. 7 gives a comparison of the fatigue strengths of two bars when the minimum stress was kept at 2 kg/mm². On the other hand, Fig. 8 shows a fatigue strength of bar (A) when the maximum pulsating stress was kept at 20 kg/mm². Some

Table 4 Mechanical properties of the material

Symbol	Yield point kg/mm²	Tensile strength kg/mm²	Elongation %
A	37.1	56.4	
B	36.3	56.8	27.5

Fig. 8 Fatigue test results of the deformed bar (maximum stress 20 kg/mm²)

scatter of the results may be attributed to the as-rolled surface condition of deformed bars.

4. Conclusion

A new resonance type fatigue testing machine has been developed, which is operated under full resonance condition. The main mass-spring system is directly excited by a simple crank mechanism, which secures stable vibration and accurate load amplitude. The amplitude itself can be adjusted continuously from zero to maximum only by changing the lever ratio of the oscillating vertical lever. Therefore, the machine is easily started and no complicated amplitude regulator is needed. In the several fatigue tests described above, the machine has proved to be satisfactory in its performance.

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