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NEW DESIGN OF CLOSED LOOP SERVO HYDRAULIC DEVICE FOR THERMAL FATIGUE TESTING

The paper presents the proposal of new design of closed loop servo hydraulic device for fatigue testing, induced by mechanical loading spectrum and variation of temperature. In addition to easier testing performance and more accurate results, the use of this solution offers significant saving in test duration and energy consummation.

Keywords: fatigue testing, thermal fatigue, closed loop servo hydraulic testing device, load spectrum simulation.

Introduction. It is of utmost importance to have the data of material response to load and environment in heavy duty equipment like nuclear and thermal power plants, or aircraft structures, which are exposed to variable mechanical loading of high intensity, combined with the thermal loading caused by variation in temperature. In these structures material is exposed to a very complex operating condition due to simultaneous effects high cycle loading and of different thermal loading due to different operating temperatures. Safe service and economical operation of thermally loaded structures require continuous monitoring of loaded material, but initial data about materials properties are precondition for successful design and use. For that, basic mechanical properties of material together with material response to complex operating conditions, consisting of high variable mechanical loading and thermal effects at different temperatures, varying in random broad limits, which can be experienced in service, present continuous problem for safe service and extended life of equipment.

Load spectrum. It is not an easy task to define and simulate fatigue loading spectrum combined with thermal fatigue. In fact, two interactive effects have to be recognized, monitored and analyzed, what is very complicated due to simultaneous changes of material properties by variable mechanical loading and in the same time by temperature variation. When these effects are individually and separately considered in experiments, the only way to get sufficiently accurate data is to model temperature effect on mechanical cycle fatigue. But only valid and fully acceptable material response is to simulate real operating conditions in unique spectrum as close as possible, and in this way to obtained valid results of loading and of temperature effects in the shortest time period. However, it is difficult to simulate even separately high cycle fatigue and temperature variation.

The simulation of loading spectrum in cycle fatigue has been solved successfully by introduction of closed loop testing equipment in 1950 [1]. Much more difficult is the simulation of thermal fatigue due to very sharp gradient of temperature change rate because this gradient is also affected with the thermal capacity of tested structure [2]. Next complication is connected with material properties change caused by variation of temperature. This problem is partly considered and solved by small sized specimens heated by induction and fast cooled by liquid gases [3], or simulating real structures and application of fluids heated to the proper temperatures using one or several heat sources [4, 5]. This approach exhibited excellent results of solution for streaming in the pipelines of nuclear thermal equipment.

Studying the problems of fatigue at variable temperatures authors have notice the possibility to apply some very interesting sophisticated solution. The solution can be applied to mechanical engineering equipment, but also it can be used to model testing of civil engineering products. In general, mechanical equipment is typically very compact, but with possible sharp change of temperature gradient, whereas civil engineering structures are of higher thermal capacity, with slower change of temperature gradient.

In the case of equipment and structures in mechanical and civil engineering the problems connected with fatigue at temperature variation requires somewhat different approach, but following the same approach and general solution.

Proposed design of closed loop servo hydraulic device for fatigue testing. In Figure 1 servo hydraulic device for fatigue testing by variable loading at high and low temperature is schematically presented.

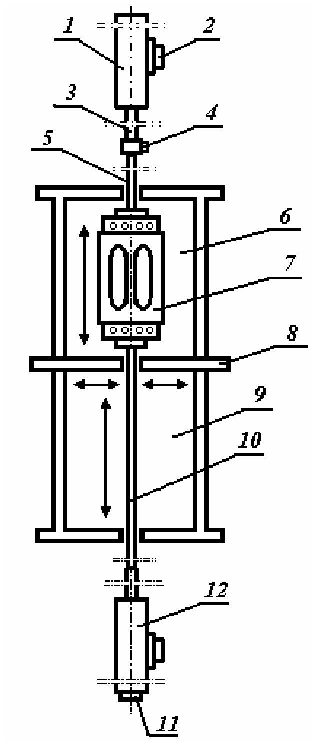

Fig. 1. Servo hydraulic device designed for fatigue testing at two different temperatures: *1* – upper servo hydraulic cylinder (actuator); *2* – servo valve; *3* – piston; *4* – load cell; *5* – extending rod, upper; *6* – upper chamber; *7* – structural specimen (sample); *8* – Insulation wall; *9* – lower chamber; *10* – extending rod, lower; *11* – linear variable displacement transducer LVDT); *12* – lower servo hydraulic cylinder (actuator).

Basically, the device consists from two chambers, upper (6), and lower (9), and two actuators - servo hydraulic cylinders, upper (1), and lower (12), acting in opposite directions, which form hydraulic closed loop. Upper chambers (6) is designed for high temperatures, and the lower one (9) for low temperatures (in this example). The chambers are separated by insulation wall (8), which can be performed in the form of two movable screens, or, in the case of specimens (7) of round cross section in the form of photographic lens diaphragm, depending on tested specimen shape and size. In operating condition this separation wall serves as a fine sealant of piston (3) hole, passing, in this case, through lower chamber. Upper actuator (1) operates in load control regime, and it is connected to load cell (4), involved to measure load. Because of dimension of load cell it is necessary to involve upper extending rod (5) between it and tested sample (7), which should assure the sealing at the entrance to the upper chambers. This rod must have sufficient length to enable an easy specimen displacement from one chamber to the other, and also to have diameter of cross section with tolerance limits assuring acceptable sealing level. However, this is the requirement only for upper rod (5) because lower rod (10) always operates in stroke control and is connected with linear variable displacement transducer – LVDT (11). Anyhow, LVDT is of inductive type, built-in into actuator, and for that does not induce any trouble and special requirements. Lower actuator (12) serves to bring the specimen in requested position (in upper or lower chamber). In presented stage the control of upper cylinder is positioned to zero loading (0 kN). This enabled to move freely the specimen from one chamber in another one, the duration of this operation is only few seconds. This very short time period of specimen transfer from low temperature chamber to high temperature chamber, and vice verse, is a valuable advantage of proposed solution.

It is to underline that this device can be constructed very easy at reasonable low expanses, since no heavy frame with the cross head is necessary, as this is the case with standard closed loop servo hydraulic machines in which hydraulic lift together with hydraulic lock are required for positioning. In fact, for new designed device it is sufficient to construct stiff structure on which the actuators and twofold chamber should be fixed following here presented instructions. Laboratories having multi channel close loop systems for testing of real structures or their models have to assure (to buy or to construct) only twofold chamber requested by testing procedure, that means to fulfill the dimensional specification and temperature testing interval. In addition, proposed solution offers significant saving in testing time and energy consummation.

Anyhow, for larger specimens the chambers of high volume are required, and it is clear that in this case that very fast change in chamber temperature is not possible. The second problem is quantum of energy which should be consumed in each temperature spectrum change.

Function of closed loop servo hydraulic device for fatigue testing at different temperatures. Based on the laboratory experience in performing load spectra experiments, including those at different temperatures, the authors envisaged the idea how to improve load spectra testing at different temperatures. The principle of device function is explained on fatigue testing with load spectra applying to structural specimen (sample), at high and low temperatures. This is presented in Fig. 2.

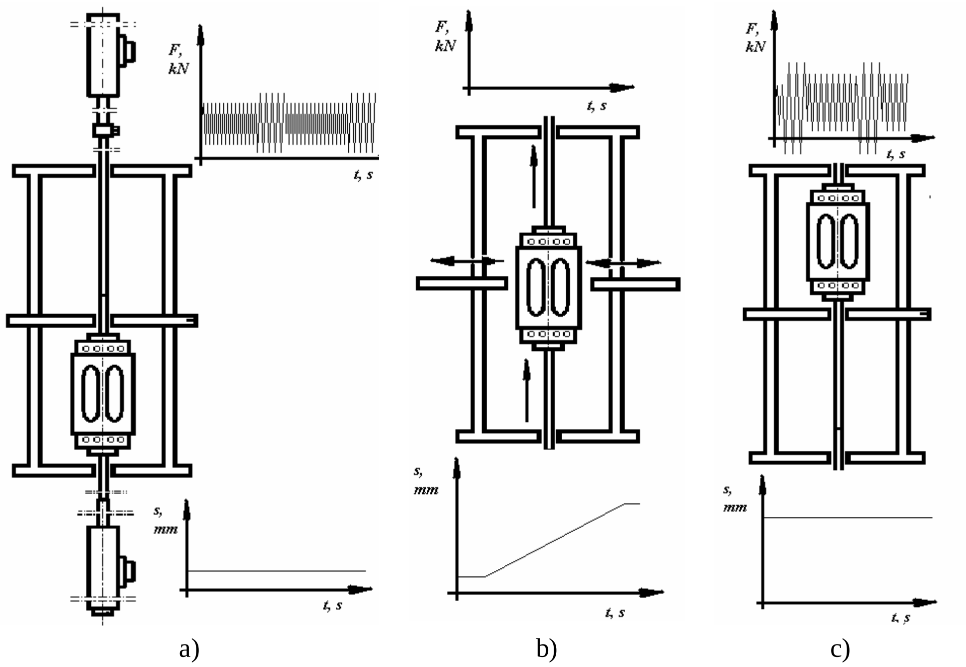

Fig. 2. Function of the closed loop servo hydraulic testing device with load control spectra of the main actuator and positioning of specimen: a) application of load spectrums in cold chamber (at low temperature); b) the procedure of changing chamber for the testing at high temperature; c) performance of testing under load spectrums at high temperature.

From the upper side in the upper chamber (6) a main cylinder is introduced, which operates in load control, except the phase of specimen positioning, fixing and removing. This means that test load spectrum is induced only through this actuator. From the lower side, in lower chamber (9) is introduced positioning cylinder, operating in stroke control. Lower, positioning cylinder has a function to select proper position for the specimen (in upper or lower chamber), that enable specimen to be exposed to high or low temperature.

Testing procedure from the positioning of specimen till its removal from the device can be described as follows. The door of lower chamber (9) are opened, both cylinders, upper (1), and lower (12) are set to stroke control to position convenient for specimen introducing. The specimen is fixed in corresponding clamps. Fine positioning is possible by switching-on upper cylinder (1) to be in load controlled, setting to nil loading (0 N). By this step in testing procedure lower cylinder can bring the specimen in required position, with no danger to load it. Now, the temperatures in both chambers can be set to test level. Only when the specimen is heated to the test temperature through the cross section, the corresponding load spectrum may be introduced by activating the main actuator (1). During this operation the positioning cylinder held the specimen in a constant position (Fig. 2,a). After this phase of testing it is necessary to bring the specimen in the chamber for high temperature. Insulation wall (8) is opened as necessary to put through loosely the specimens and appliances, Fig. 2,b. The form of big opening should correspond to specimen transverse profile. For the zero load settled

(0 N) positioning cylinder (12) pushes the specimen in the upper chamber (6) to required position. In the instance when specimen passed insulation wall zone, the wall closes assuring fine sealing between the chambers. Depending on specimen size, the phase of temperature spectrum change lasts few seconds. Positioning cylinder bring the specimen in required position and held it in this position, Fig. 2,c. The main cylinder starts to convey corresponding load spectrum when the specified temperature is reached, i.e. when test program requirements are satisfied. The described cycle will be repeated with the new specimen.

It is to underline the capacity of the device in recording and loading. Two types of records are presented in Fig. 2, the change of load *F* (in kN) vs. time *t* (in s), which corresponds to upper actuator, and stroke displacement *s* (in mm) vs. time *t* (in s), corresponding to lower actuator. Upper actuator convey load spectrum, previously defined experimentally in real service condition of a structure for corresponding operating temperature. For that this actuator is active only in variable load testing performance by load spectrum (Fig. 2,a, at low temperature, Fig. 2,c, at high temperature). In these testing conditions lower actuator is inactive, that is its function is just to hold the specimen in selected position indicated at corresponding level. In Fig. 2,b lower actuator operates in stroke control, performing movement from lower to upper level, whereas upper actuator is silent, held at zero load.

Conclusions. The basic advantage which can be gained applying proposed design of device is to shift the specimen form one temperature to another in simple way and in very short time. This will allow to shorten the time for testing, on one hand, but also to reduce the expanses for testing, saving required energy.

However, proposed solution is limited by the size of specimen, and there is probably an optimum for specimen size in this application.

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Резюме

Представлено новое серво-гидравлического устройство с замкнутым контуром для усталостных испытаний в широком спектре механических нагрузок и при высоких и низких температурах. Наряду с более доступными испытаниями, большей производительностью и более точными результатами предлагается значительная экономия продолжительности испытания и потребляемой энергии.

Ключевые слова: испытания на усталость, термическая усталость, серво-гидравлическое устройство с замкнутым контуром, моделирование спектра нагрузок.

Резюме

Представлено новий серво-гідравлічний пристрій з замкнутим контуром для втомних випробувань в широкому спектрі механічних навантажень і при

високих і низьких температурах. Поряд з більш доступними випробуваннями, більшою продуктивністю і більш точними результатами пропонується значна економія тривалості випробування і споживаної енергії.

Ключові слова: втомні випробування, термічна втома, серво-гідравлічний пристрій з замкнутим контуром, моделювання спектру навантажень.

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