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A SYSTEM FOR TESTING MATERIALS IN LONG-TERM MECHANICAL AND THERMAL LOADS

Key words

Creep, creep-testing device, accelerated creep test, low-cycle fatigue.

Abstract

The article presents a system for testing materials used in manufacturing machinery elements operating in high stresses and temperatures. An essential element of the system is a multi-purpose device for performing normative creep tests (PN-EN ISO 204) and dedicated tests for low-cycle loads and various profiles of temperature changes. The device works with two databases: collecting the results of strength tests and collecting data used in predicting time of the damage of materials. The article describes the functionality of the individual system components and gives examples of the conducted strength tests.

Introduction

Creep tests are a well-known type of materials testing. They are usually conducted in the vertical creep-testing devices in which the uniaxial stress on the sample is obtained by gravity and calibrated weights or by electricity using the motor with the appropriate control. Both types of creep-testing devices have a multi-section heating chamber that provides the required temperature of the sample. However, such devices are not keeping up with trends in the development of materials research. One of them is the development of methodologies for less time-consuming assessments of the creep resistance of the material. Classical creep-testing machines are of little use in conducting this type of research. For the new methods, there are devices being developed that can generate low-cycle thermal-mechanical loads, cyclic creep-to-rupture load types, and creep tests as a function of the indentation depth, which can measure the creep rate [1, 2, 3]. The article presents the author's own solution in the form of a system for long-term strength tests. The main feature of the system is a device that can carry out normative creep tests and user-programmable tests, including the low-cycle loads and stress in variable temperature profiles. An important element of this system is a database of tested materials, where test-run results can be automatically recorded in addition to other useful parameters in the calculation of strength. The system allows researching assessment methods for materials in machinery construction, especially those working in conditions of variable loads and high temperatures.

1. The design of the device

The design of the device (Fig. 1) uses the framework structure for a stable resistance to constant loads, characteristic for long-term creep tests, which fall within the range of up to 50 kN. Performance elements constitute a hybrid system containing the following: elements of the modified upper lever with regulated gear ratios and an additional counterweight to balance the lever with different gear ratios, electric synchronous motor, and load creep-tester. In gravitational load, the sample stress comes from the weights placed on a pan connected with a chain connector to the side lever. In a system with a servomotor, the connector is articulately linked with a table that can be moved vertically, and thus can exert the desired load or strain. The motion of the table along the rolling guides is regulated by the signal from the tensometric force transducer mounted in the path of the load or the measuring system of the strain in the sample.

There also is an option of using feedback, which allows free modification of the load characteristics in the course of research. When using gravity load with the moving table constructed with the screw-roll mechanism, it is possible to implement a cyclical loading and unloading of the sample. Additionally, movement of the table following the elongation of the sample secures the load system in case of rupture during the test.

Heating the sample takes place in the two-section oven equipped with heaters G_1-G_4 (Fig. 2). The temperature is measured by two thermocouples (temperature T_g and T_d) placed directly on the sample. An important feature of the heating oven, not common in these types of devices, is the option of opening the lower or the upper outlet (which allows the introduction of additional sensors for monitoring the status of the sample) and the cooling system that uses forced airflow.

a) b

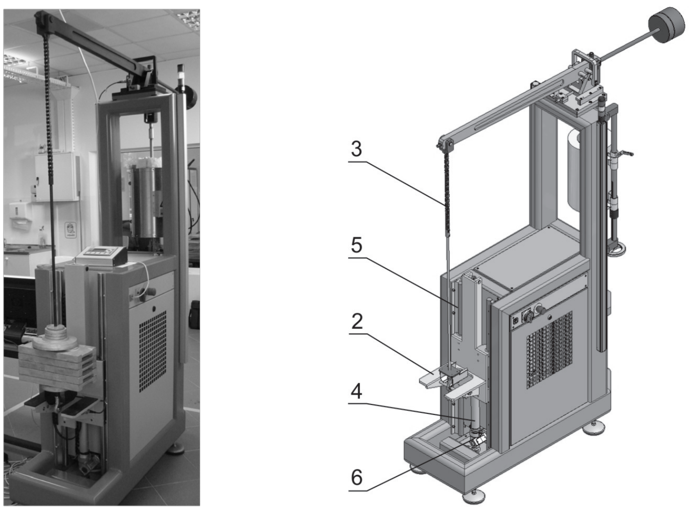

Fig. 1. The view of the device with gravitational load (a) and using the electric motor (b) 1 – weights, 2 – table, 3 – connector, 4 – screw-rolling mechanism, 5 – rolling guides, 6 – synchronous motor power supply

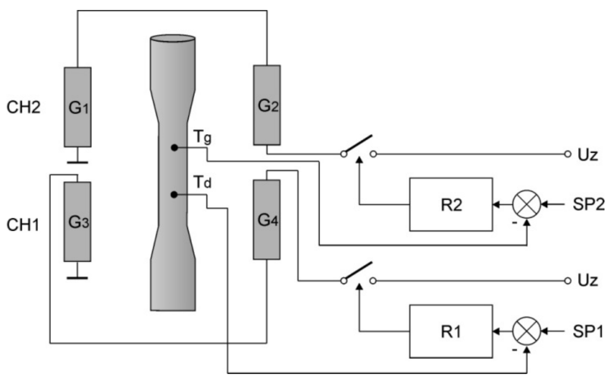

Fig. 2. A diagram of the measurement system and temperature control in the heating chamber

Temperature regulators *R1* and *R2* use a PID control algorithm with variable parameters adjustments (gain scheduling). The alteration in the parameters is automatic for specific temperature ranges. The accuracy in adjustment obtained for normative test is the full-range of 0.2°C up to the maximum temperature of 1,200°C (Fig. 3). The maximum temperature is reached within 1.2 h. Uncontrolled cooling from this level, down to 100°C, takes 9h. When using the cooling system, this time is reduced to about 1h. The turning on of the cooling system turns off the heater temperature control with resistance heaters H_t, H_b, while maintaining the measuring path and temperature monitoring feed.

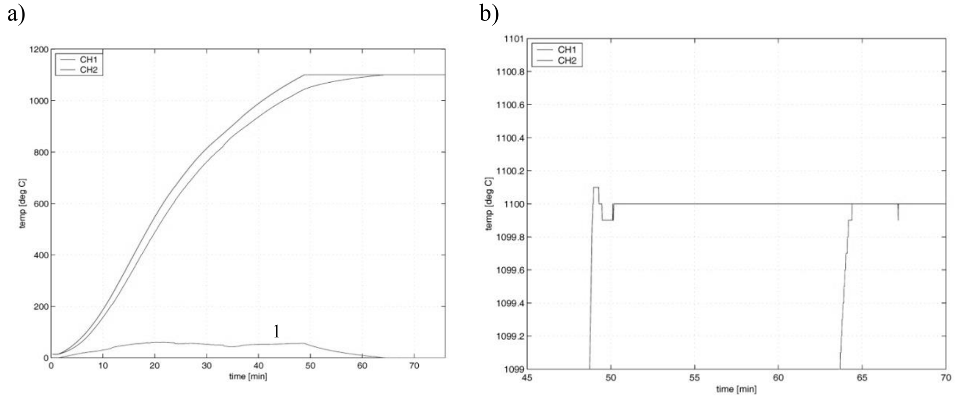

Fig. 3. The process of temperature control of the lower (CH1) and the upper (CH2) part of the sample while approaching the set value of 1,100°C. Line No. 1 on the Fig. 3a – a momentary temperature difference (CH2-CH1)

The power system uses a synchronous motor with a VSD (Variable Speed Driver). Accuracy adjustment has been obtained at the level of 7 N, in the range from 0 to 35,000 N. The force increase rate is set within the non-unit range of v = 1 to 6000. The actual values for the constant temperature range are from 3.9 to 500 N/s for a range of 1 kN (Fig. 4a).

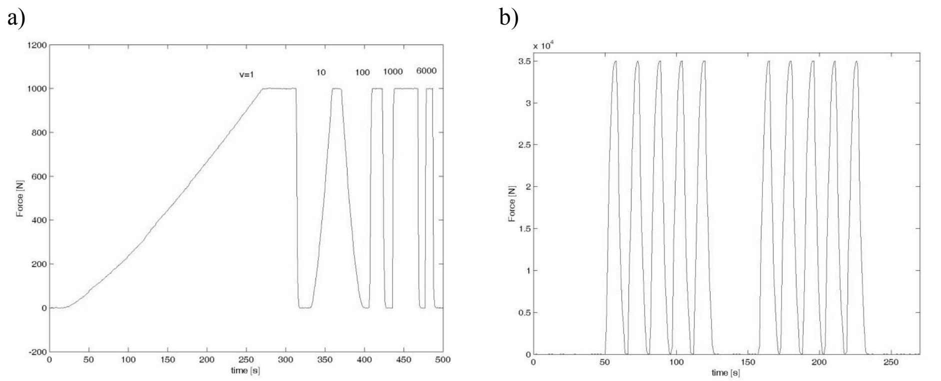

Fig. 4. The chart of the time of the force increase for different velocities of the synchronous motor (a), and cyclical loads for the maximum parameters of force and rotational velocity of the synchronous motor (b)

The obtained durations in force changes allow the estimation of the number of cycles that are possible to perform at reasonable intervals, in low-cycle fatigue research. For maximum parameters of cyclical loads in the system with a force regulator and maximum velocity v = 6000, the obtained cycle period is T = 15.4 s and force increase rate is 4,545 N/s (Fig. 3b). These parameters give the following durations in flow-cycle fatigue tests: 10^3 – 4.17 h, 10^4 – 41.67 h, 10^5 – 416.67 h, and so on. Due to the durations of tests, the devise is designated to work in low-cycle load testing in the 10^4 – 10^5 cycle range.

Programming for a run of normative tests, in accordance with the PN-EN ISO 204 norm, is done automatically by specifying parameters of the sample, example stress, points of the measurement of stress and strain, the temperature of the sample, a condition for the completion of the creep test, and creep values for which obtained duration values are reported.

Programming for testing with changeable parameters is carried out using the batch control method. The device implements basic commands, whose parameters determine the conditions for the subsequent phases of the test. Sequential execution of the subsequent basic commands ensures the desired course of the test.

2. Software for data collection and analysis

The materials engineering methods and techniques employ metallographic tests and the testing of mechanical properties for the assessment of the working condition of an item in terms of creep and its suitability for further service. The adaptation of the equipment for such an assessment is based on its cooperation with the two databases: the database for measurements that collects the information obtained in the creep tests and the database of materials containing parameters of the test material properties, containing detailed description of the material and has the capabilities to include the description of creep tests performed by the device (Fig. 5). Both databases use standard database streaming (Citadel, Oracle).

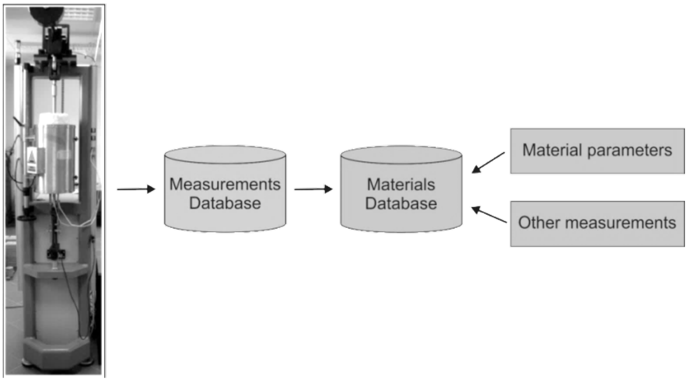

Fig. 5. The structure of the information collection in the software of the device

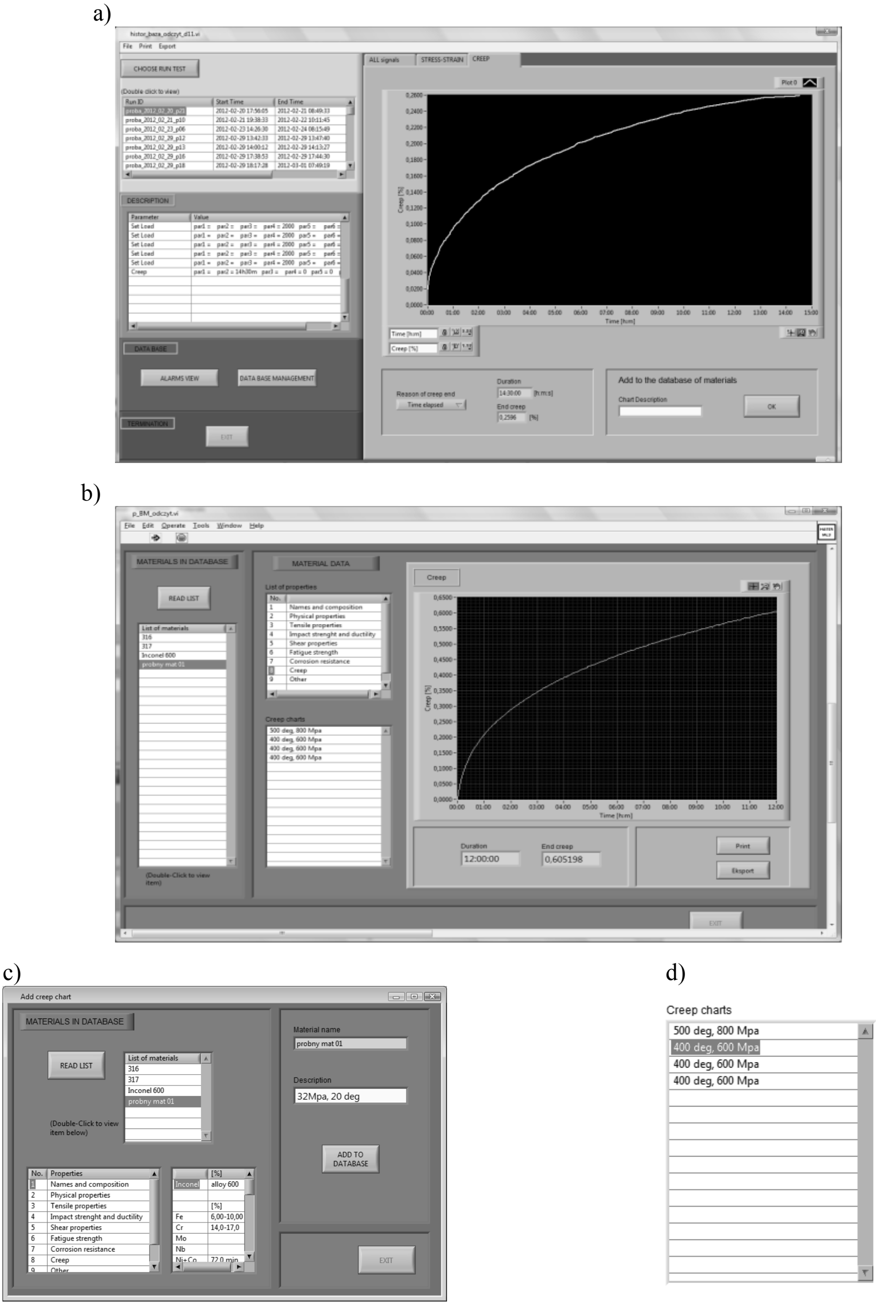

Fig. 6. Screenshots of the software windows for the implementation of creep charts from the measurement database to the materials database: a) the measurement database window); b) the materials database window; c) window for adding a description of the material; d) the window for selecting saved creep charts for a give material

The measurement database contains procedures for saving and retrieving the following objects: all measurement signals, a full test description, alerts, and charts (stress-strain, creep). The features implemented in the software of the measurement database are the following: connecting test runs, printing charts, reporting, test run export, and database management.

The description of the material in the database is divided into the following groups: name and chemical composition, physical properties, tensile test, impact strength and plasticity, shear strength, fatigue strength, corrosion resistance, creep, and other parameters.

The information in the description of "creep" is derived from the database of measurement. Their inclusion in the database occurs in the sub-programme of the measurement data base management (Fig. 6a). The procedure of chart inclusion (Fig. 6c) allows attaching to the designated material any number of creep charts. Reading of the runs (Fig. 6b) takes place by selecting the chart name entered by the user (Fig. 6d).

The group in the material description ("other parameters") allows entering any data (numeric and text) in a two-dimensional array. It can contain graphically designated values of the functions related to the material research, general forms and parameters of the approximating functions for measuring runs, and analysed results of test runs and superposition runs performed with specific parameters.

3. Setting the parameters of strength tests

The programming of the device is done in a "batch" system [5]. Each test, regardless of whether it is done according to the creep norm of uniaxial tension (PN-EN ISO 204) or according to the user settings, is programmed in the device (a computer directly managing the device) or an external spreadsheet. The programming consists in filling in a table with the basic commands. Each command has the appropriate parameters. For example, *Load (V, F)* command means loading the sample with a force of value *F*, with the increase velocity of *V*. The set of commands includes all possible functions arising from the construction of the device and its hardware. An example of the implementation of a normative test programmed in this way is shown in Figure 7.

This way of programming tests also allows an adequate simulation of the actual loads on materials [6].

An example of such a process of simulation (Fig. 8) is a repetition of stress changes (*stress_r*) and temperature (*temp_r)* on a steam boiler element. Other types of tests may include a combination of temperature changes with cyclical loads.

The device can perform automatic hybrid tests, combining normative creep tests, low cycle loads, variable amplitude and frequency loads, and programmable temperature changes.

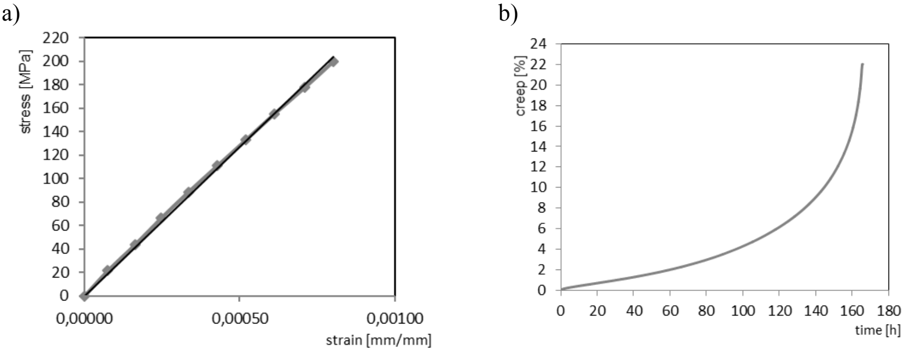

Fig. 7. The results of the normative measurements – characteristics of stress-strain (a) and creep chart (b)

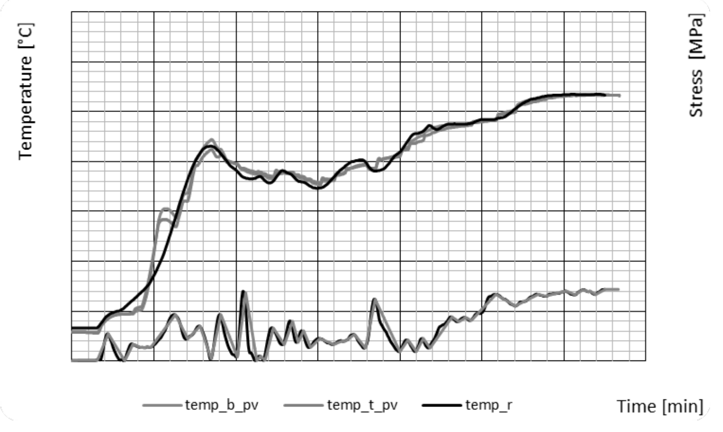

Fig. 8. The simulation of actual operating conditions of the an electric device: temp_b_pv – parameter value of the lower part of the sample, temp_t_pv – parameter value of the upper (CH2) part of the sample, black lines – temp_r, stress_r (temperature and stress from real object)

Conclusions

The designed and manufactured device is an innovative research tool. Its control system uses advanced control algorithms. Consequently, the precision of the temperature control and strength exceeds the requirements of the norm on creep in uniaxial tension. Tests carried out in accordance with this standard are supported by the following: calibration procedures for path measurement, automatic reporting of test results, and procedures for manual and automatic interruption and resuming of testing.

An analysis of the results is facilitated by the cooperation with the two databases. The measurement database collects information about the parameters of the tests carried out. The material database contains selected information from the measurement database and additional data describing the material.

Test programming takes place in the device or in a spreadsheet. This is coupled with the batch test method, which is a selection of commands carried out by the device, and the construction solutions of the heating oven enables the user to generate their own tests with programmable temperature and stress changes, including tests recreating the actual conditions of the machinery functioning in high temperatures and increased pressure.

Adequate simulation of various loads of machine components allows conducting research on new ways to fast-track research of materials and the prediction time of damage to critical machine components.

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References

1. Mandziej S.T.: Accelerated creep testing of new steels for power generation and chemical processing. Proceedings of Conference Metal 2010, paper 72.
2. Woodford D.A.: Accelerated Testing for High-Temperature Materials Performance and Remaining Life Assessment (EPRI, Palo Alto, CA: 1999, TR-114045).
3. Izaki T. et al.: A creep life assessment method for boiler pipes using small punch creep test. International Journal of Pressure Vessels and Piping 86 (2009), pp. 637–642.
4. Samborski T., Zbrowski A., Kozioł S., Majcher A.: Mechatroniczne stanowisko do badań zmęczeniowych. Energetyka, Zeszyt tematyczny nr XXII, listopad 2011, s. 76–79.
5. Majcher A.: Programowanie dedykowanych testów badawczych w urządzeniu do badań pełzania przy jednoosiowym rozciąganiu. Pomiary Automatyka Kontrola PAK vol. 59, nr 4/2013, s. 349–352.
6. Majcher A., Weglowski B., Oclon P.: Multi-function device for creep testing at elevated temperature. Advanced Materials Research, Vols. 875–877 (2014) pp. 462–466.

System do badań materiałów w warunkach długotrwałych obciążeń mechanicznych i termicznych

Słowa kluczowe

Pełzanie, pełzarka, przyśpieszone badania pełzania, zmęczenie niskocyklowe.

Streszczenie

W artykule przedstawiono system do badań materiałów stosowanych do wytwarzania elementów maszyn pracujących w warunkach podwyższonych naprężeń i wysokich temperatur. Podstawowym elementem systemu jest wielofunkcyjne urządzenie umożliwiające wykonywanie normatywnych testów pełzania (PN-EN ISO 204) oraz dedykowanych testów o obciążeniach niskocyklowych oraz różnych profilach zmian temperatury. Urządzenie współpracuje z dwiema bazami danych – do zbierania wyników testów wytrzymałościowych oraz do zbierania danych materiałowych wykorzystywanych w predykcji czasu do uszkodzenia. Opisano funkcjonalność poszczególnych elementów systemu oraz podano przykłady przeprowadzonych testów wytrzymałościowych.