A PROTOTYPE WORKSTATION FOR FATIGUE TESTING OF A YOKE TYPE FORGING

Paweł JABŁOŃSKI [1], Marek HAWRYLUK [1], Jacek ZIEMBA [1], Marcin RYCHLIK [1]

[1]*Wroclaw University of Science and Technology, Wyb. Wyspiańskiego 27, 50-370 Wroclaw, Poland, EU*
pawel.jablonski@pwr.edu.pl , marek.hawryluk@pwr.edu.pl , jacek.ziemba@pwr.edu.pl , marcin.rychlik@pwr.edu.pl

Abstract

The article deals with the matter of development of a prototype of fatigue test bench for fork type forging, with particular emphasis on the measurement-archiving application that allows to determine magnitude of moment of force and rotation angle in time. These forgings are used for steering columns and are a critical element of car safety. Due to the nature of the variability of loads applied to the element, its high fatigue strength is crucial, both in low and high-frequency cycles. For this reason, they require special quality control during production process, development of advanced manufacturing techniques and ensuring their repeatability. Unfortunately, in the case of matrix forges, no strength tests are carried out for these forgings, which means that after heat treatment, they may have different mechanical properties. The construction of the workstation is intended to enable conducting of fatigue strength tests. For its operation web application, was developed in Python (with the use of Flask library and SQLite database), which enables control, collection and analysis of data obtained during the process. Thanks to this, it is possible to execute set number of fatigue cycles, measuring the inflection angle and torque, and detecting cracking of the tested material. Further development of the station is planned in the future, in order to analyze the impact of the applied heat treatment on fatigue strength, creating added value for the end customer.

Keywords: Durability of yoke type forgings, development of a prototype fatigue bench

1. INTRODUCTION

Currently, hot stamping is performed with many components that are often used as parts of machines with increased load capacity. Such elements are used widely in the agricultural, mining and automotive industries, among others in such components as the steering or drive system of the vehicle, from which, besides high mechanical and quality properties, high fatigue strength is often required [1-3]. In example, yoke type forgings after appropriate heat and mechanical treatment are used, among others, in steering columns, where they are a critical element of car safety [4]. Due to the nature of the variability of loads to which such an element is subjected, its high fatigue strength is very important, also low-cycled, because with too large twisting angles, plastic deformations may appear [5-7]. For this reason, they require special supervision during the forging process as well as conducting many tests and validation tests after the manufacturing process, in order to ensure repeatability of the production process and meet specific customer requirements (e.g. hardness, microstructure, etc.). For that reason forgings are subjected to thermal treatment - normalizing, in order to obtain a suitable homogeneous microstructure, ensuring assumed high mechanical properties. Unfortunately, due to their complex geometry, after such a heat treatment for a whole batch of forgings, they may have a slightly different structure. It causes also changing the mechanical properties, and thus different fatigue durability. Therefore, it seems reasonable to carry out additional comparative tests regarding the determination of fatigue strength, taking into account, for example, the influence of the applied heat treatment on the number of cycles to failure or the occurrence of plastic deformation. Such tests in the case of forgings with complex geometry require an individual approach and construction of a test bench for a specific assortment [8]. Such stations are often equipped with a number of measuring sensors like: force, displacement, bending moment, twisting or deformation angle. The most frequently used ones include encoders, extensometers, strain gauges or also torque sensors [9]. Machines for strength tests should also be characterized by a modular structure, enabling their modernization and expansion, and have appropriate software to ensure control, size measurement and archiving of the results. The results obtained thanks to such stations, may also constitute an added value for the end user, because they may constitute an additional argument in the case of vehicle safety.

The purpose of the work is to present a prototype design for a fatigue test (high and low cycled) for yoke type forgings, with particular emphasis on a user-friendly application allowing to determine the course (torque and rotation angle) and archiving obtained results.

2. DESCRIPTION OF THE ANALYZED PROCESS

The forged element is performed on the Massey press with the nominal pressing force of 13 MN, with the crank angle of 127 mm, crank length of 610 mm and press frequency of 90 strokes per minute (**Figure 1**).

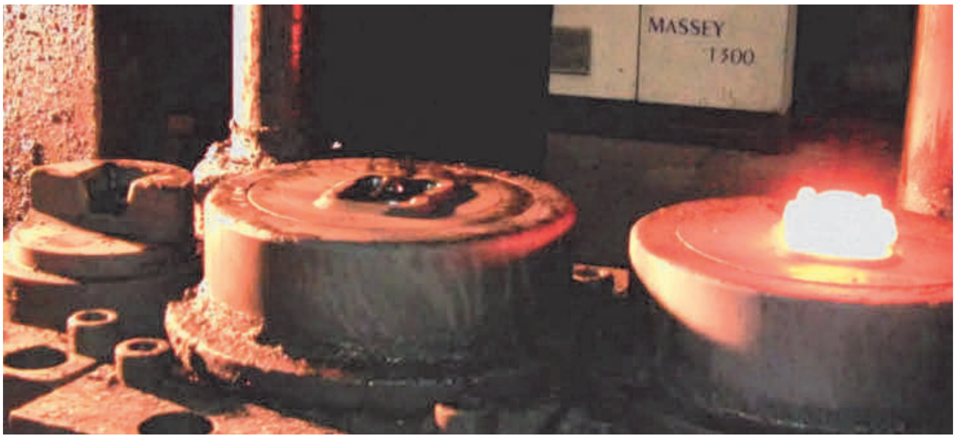
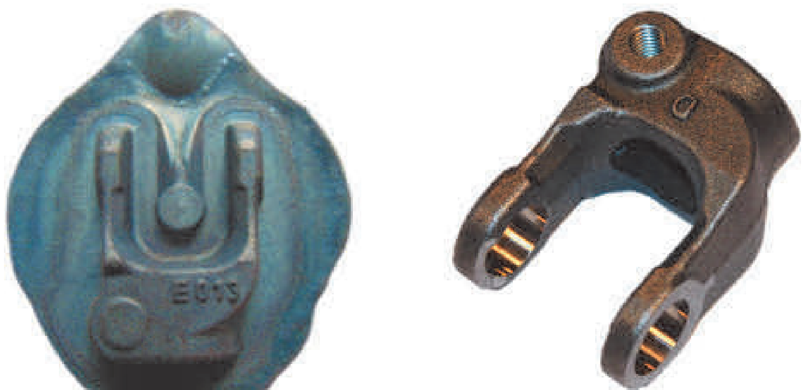


Figure 1 View of the forging process

Figure 2 presents example of yoke type forging and element, which is a part of the steering gear of a passenger car.



a) b)

Figure 2 a) yoke type forging with flash, b) ready to use part after mechanical processing

This forging is made of C45 steel. Forging's weight is 0.32 kg. The batch material is heated to 1120°C -1150°C and then subjected to 3 hot forging operations. In the first operation of forging, the batch material is swaged and then flattened. Further forging operations shape the material into final product. After these activities, the cooled element is trimmed - the flash is separated from the usable part. In the last production stage, the element is subjected to controlled cooling and finishing.

3. DEVELOPMENT OF A PROTOTYPE FATIGUE BENCH

In order to carry out fatigue tests of the yoke, the stand was designed and created. **Figure 3a** shows the draft of the workstation and **Figure 3b** presents the final product. Tested element is fixed to the base of the station on one end, the other end is attached to a driven lever which imparts a set load on the forgings, bending them. The movement of the lever is carried out by rotating cam. Cam's height defines the maximum bend angle of the forging. The whole mechanism is powered by an electric motor with 3kW of power and a rotational speed of 1500 min^{-1}, through a bevel gear transmission with 24:1 ratio. Use of inverter allows for smooth change of motor's speed. In order to measure the bend angle of the tested forging, an encoder was installed on the axis of rotation of the element. Additionally, a torque sensor was placed on the main drive shaft. The measuring station is controlled via a desktop computer. In the initial testing phase, a simple application in LabView environment was created to record data from the angle and torque sensors.

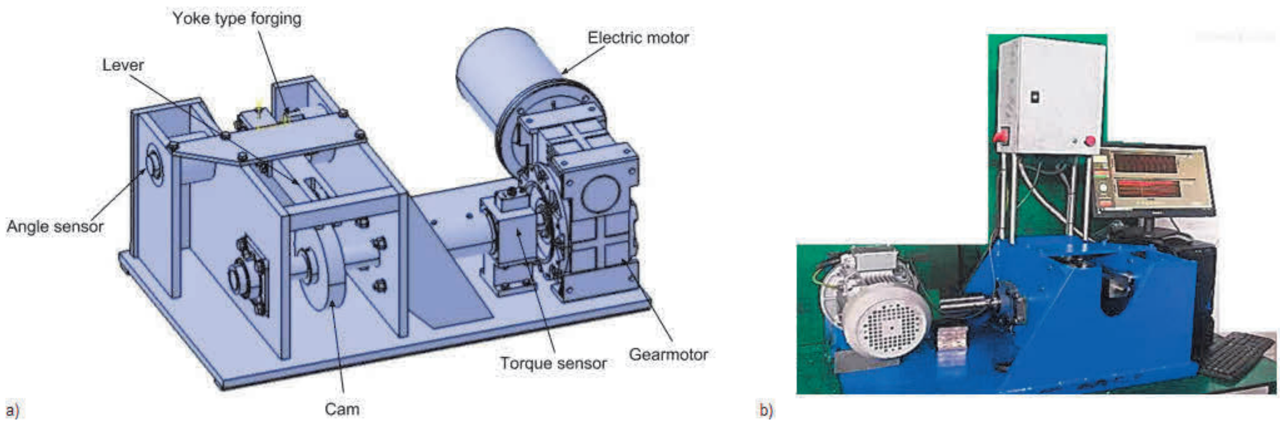


Figure 3a) Diagram of the most important components of the bench, **b)** The built station for testing durability of the forgings

Conducted tests and analyzes using numerical modeling allowed to determine the magnitude of the torque causing deformation of the element. **Figure 4** presents the results of computer simulations for forgings concerning the determination of the torque magnitude on the occurrence of plastic deformation, using the Marc Mentat software. On this basis, a research methodology was proposed for the bench, a comparative method for various yoke type forgings and variants of the heat treatment. It was decided to conduct two types of durability tests: low-cycled (causing permanent deformation after a few cycles) and long-cycled (resulting in the destruction of the element after several tens of thousands of cycles).

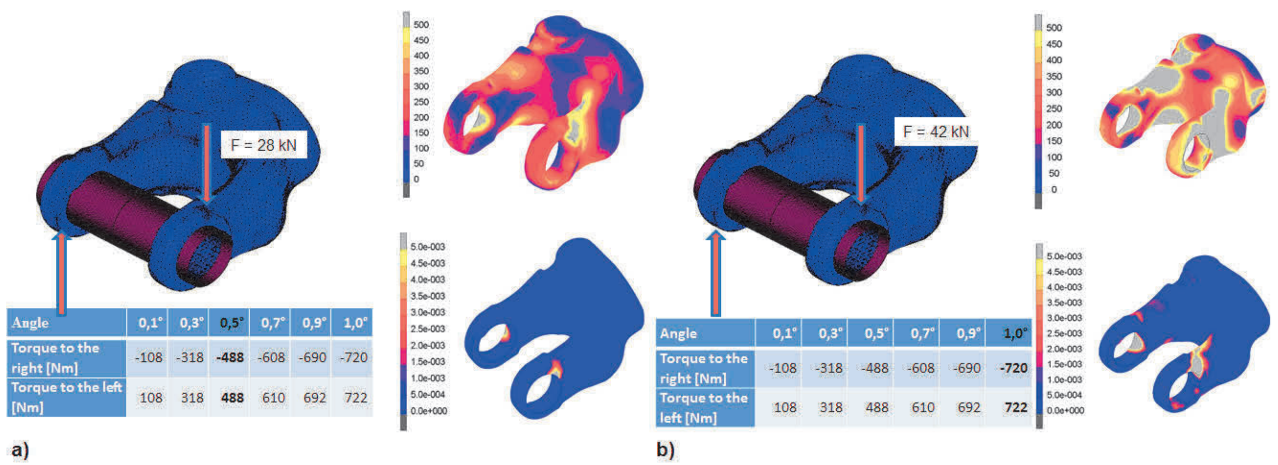
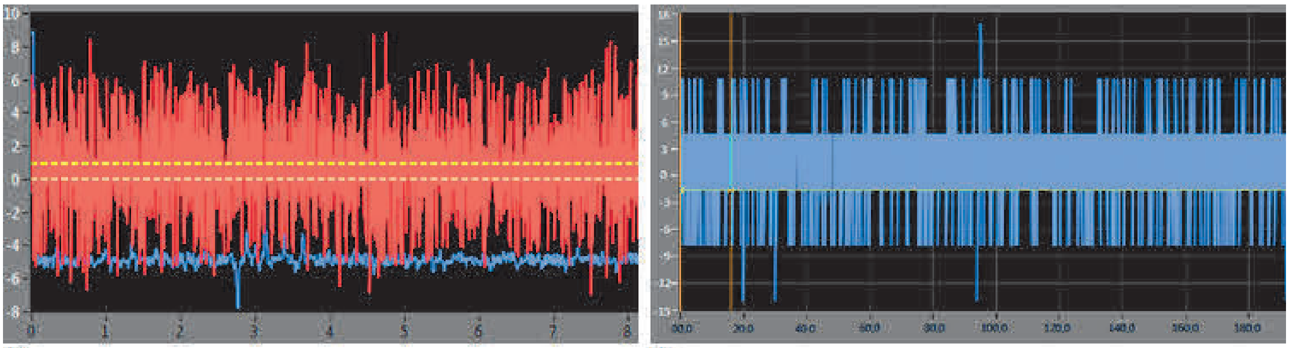


Figure 4 Stresses and deformations at a) long-cycled tests - 0.5° b) low-cycled tests - 1°

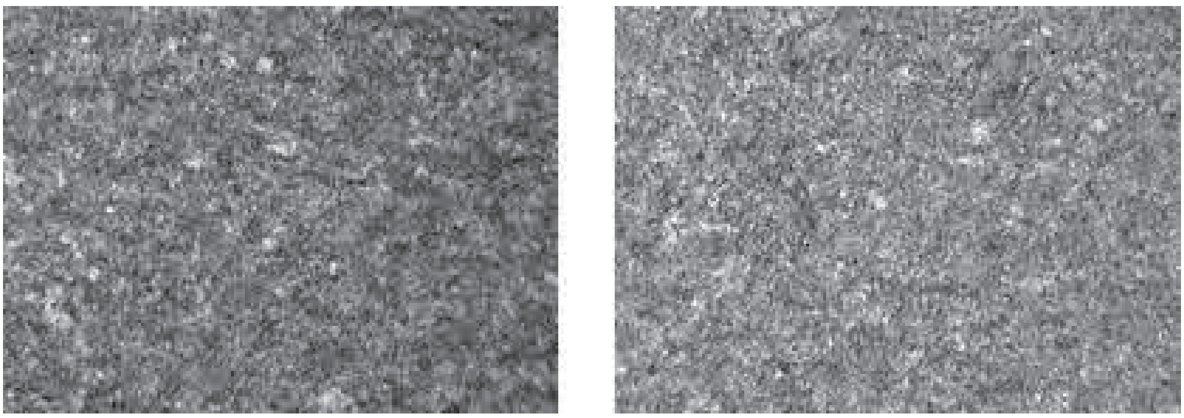
Figure 5 presents the torque values in time obtained from the torque sensor at the station for various variants of fatigue tests made via first version of the software.



a) b)

Figure 5 Diagram of the torque course versus time for forgings **a)** in low-cycled tests (maximum torque *M* = 768 Nm recorded), **b)** in long-cycled tests (maximum torque *M* = 432 Nm recorded)

In the presented case (**Figure 5a**) it was observed that for the forging subjected to low-cycled tests, the forks was clearly deformed (maximum torque 768 Nm recorded after 1 cycle), while for the forgings after the same heat treatment option, subjected to the long-cycled (**Figure 5b**) test a crack in the fork was observed, at 451342 cycles (the maximum torque *M* = 432 Nm was recorded). For the presented case, after a given heat treatment, the sorbitol structure shown in **Figure 6a** was obtained. However, for a different variant of heat treatment, a sorbitol structure with ferrite separation was obtained (**Figure 6b**)



a) b)

Figure 6 a) Sorbitic microstructure + ferrite separation + small perlite precipitations obtained for the forging after heat treatment; **b)** Sorbitic microstructure + ferrite separation

The preliminary tests of the bench showed that it is necessary to reconstruct the application and the control system due to the low flexibility of service and low immunity to external interference.

4. SOFTWARE DEVELOPMENT

The next step in development of the bench was to modernize the control system and create new software that allows full control, acquisition and archiving of collected measurements. For the processing of data from analog sensors (angle sensor - 0 - 10 V and torque sensor - 0 - 20 mA), the measuring analog inputs of the inverter were used. This solution is possible due to the high 16-bit resolution of the analog-to-digital converter used in the measuring system of the inverter with a sampling frequency of 2 MSPS. Both sensors used have a 12-bit resolution. Thanks to this configuration it is possible to meet the requirements set for the measuring system, without the need for expensive measuring cards. **Figure 7** presents the construction of the measuring system of the analog inputs inside the inverter.

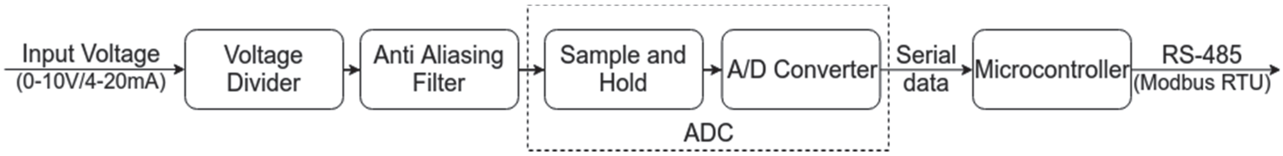


Figure 7 Internal structure of the measuring system inside the inverter

The inverter has been configured to convert analog data into to digital format. Then the all data, along with the parameters of the inverter, are exchanged with the application running on the computer. Data transmission on the computer-inverter line takes place via the RS-485 bus with the Modbus RTU protocol. This solution ensures operational reliability and fast data transfer without interference.

Due to the long duration of a single test, up to several days, it was decided to create a web application that will allow remote access from any device with a web browser. The program was developed in Python language using the Flask library. After logging in, users can start a new measurement session or load previously created data for analysis or completion of the measurements. When creating a new project, it is possible to enter the name of the test and its optional description for easier identification later.

After creating a new project or loading an existing session, the user can start the process by pressing the "play" button or stopping the active test with the "stop" button, both located in the top menu (**Figure 8a**). The data is recorded on an ongoing basis into the SQLite database on the computer. At any time, user can export the collected data for further analysis to the XLS file, by clicking the button located in the top menu. Before starting the test, it is possible to set motor speed using the arrows located next to the value of speed in the process data window. Speed can be set from 100 to 1500 min^{-1} (**Figure 8b**).

Figure 8a) Top menu buttons, **b)** Settings of motor speed

The chart presents the current course of the inflection angle of the tested forging as a function of time. This graph is generated by using the Highcharts library (**Figure 9**).

The process data window contains information about the current speed, the number of executed cycles and the maximum recorded angle of inclination. In case of an event such as tested element breaking or failure of the measurement system, a message will appears in the alert window. In addition, an e-mail message is sent to the user. Destruction of the tested element is detected if the value of torque decreases below set minimum or inflection angle exceeds the limit. After the event occurs, the process is immediately stopped, allowing for the user to register exact number of cycles. Data transmission between the application and the inverter is carried out using the Modbus RTU protocol. On the application side, the pyModbus library was used for this purpose. The measurement data are exchanged at a frequency of 1 kHz. Due to the high frequency of queries sent, it was necessary to set a higher transmission speed. It was set at 115 200 kbps.

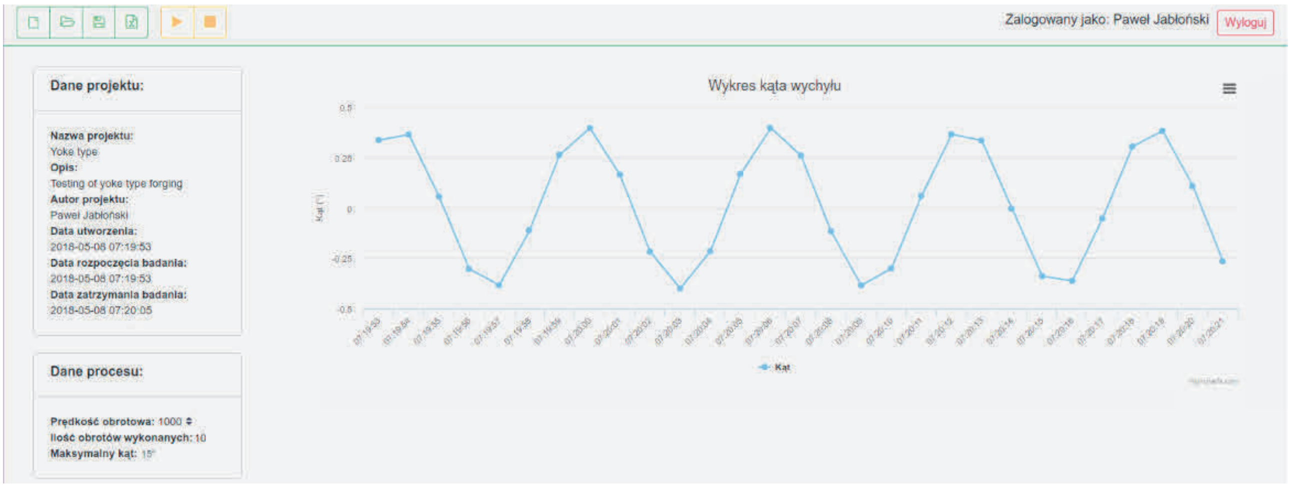


Figure 9 Main window of the developed application

5. CONCLUSION

The paper presents a prototype station for fatigue testing of yoke type forgings, including the development of a measurement-archiving application developed in Python using the Flask library. The built-in bench allows for two types of tests depending on the twisting angle determined on the basis of FEM: low-cycled tests (for 1º angle) and long-cycled (0.5º angle), which can be obtained by using different cams. The developed control has been significantly simplified by eliminating the expensive measurement card, because the inverter's measuring system provides sufficient parameters for reading the measurements obtained from the sensors. Further development of the software will be directed to the use of other data received directly from the inverter, such as the current engine power or torque to compare the values with the sensor readings. The presented examples of research results show what a significant influence on the structure, responsible for the properties and shape of the forgings is the type of heat treatment carried out. Currently, further evaluation work is underway related to the proposed research methodology. The research results undoubtedly add value to the product and tighten cooperation with current and future recipients.

REFERENCES

[1] KOCAŃDA, S. and KOCAŃDA, A. *Niskocyklowa wytrzymałość zmęczeniowa metali*. Warszawa: PWN, 1989.

[2] SZUSTA, J. and SEWERYN, A. Low-cycled fatigue model of damage accumulation - The strain approach. *Engineering Fracture Mechanics*. 2010. vol. 77, pp.1604-1616.

[3] SEWERYN, A., BUCZYŃSKI, A. and SZUSTA, J. Damage accumulation model for low cycle fatigue. *International Journal of Fatigue*. 2008. vol. 30, pp. 75-76.

[4] DWORZAK, Ł., HAWRYLUK, M. and ZIEMBA, J. Wear analysis of die inserts in the hot forging process of a forked type forging using reverse scanning techniques. *Advances in Science and Technology Research Journal*. 2017. vol. 11, pp. 225-238.

[5] MARINES, I., BIN, X. and BATHIAS, C. An understanding of very high cycle fatigue of metals. *International Journal of Fatigue*. 2003. vol. 25, pp. 1101-1107.

[6] BATHIAS, C. and PARIS, P.C. *Gigacycle Fatigue in Mechanical Practice*. New York: Marcel Dekker, 2005.

[7] FAJDIGA, G. and SRAML, M. Fatigue crack initiation and propagation under cyclic contact loading. *Engineering Fracture Mechanics*. 2009. vol. 76, pp. 1320-1335.

[8] MAJ, M. Problematyka badań zmęczeniowych w oparciu o kruche pękanie i niskocyklowe próby zmęczeniowe (LCF i MLCF). In *XXXIII konferencja naukowa z okazji Ogólnopolskiego Dnia Odlewnika 2009*. Kraków: AGH, 2009.

[9] MACHA, E., KASPRZYCZAK, L., MIREK, G. and TRENCZEK, S. Układy sterowania elektromechanicznych maszyn zmęczeniowych. *Mechanizacja i automatyzacja górnictwa*. 2009. vol. 47, no. 5, pp. 21-30.