MODERN MATERIALS IN AEROSPACE INDUSTRY - FATIGUE TESTS OF MAGNESIUM ALLOY CONTROL SYSTEM LEVER OF THE UNMANNED ILX - 27 HELICOPTER

Małgorzata Wojtas*, Agnieszka Sobieszek*, Łukasz Czajkowski*, Rafał Żurawski*
***Institute of Aviation,**

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Abstract

Paper presents new technology and materials applied in aerospace engineering. As an example, a main rotorcraft control–system lever is shown in studies aimed at approving the new material. The goal is to approve a new, lighter material i.e. AZ31 magnesium alloy, which will have the appropriate strength properties. The aim of implementing such amendments is to minimize the weight of an unmanned ILX-27 helicopter designed at the Institute of Aviation. Determination of static and dynamic strength of the lever is the basis for pre-determining the viability and approval of a new structural part for flight.

In this project the fatigue tests of magnesium alloy AZ31 control-system lever of the ILX -27 unmanned helicopter was carried out. Test program of the lever is based on real data from flights of the ILX-27. Tests were performed on a test stand dedicated directly to the fatigue tests of the control lever and designed in such a way to accurately reflect the control-system lever loads occurring during the helicopter flight. Fatigue test had to give the answer about the strength of the control-system lever for up to 100 hours of flight of the unmanned helicopter ILX-27. Before proceeding to fatigue tests, we conducted a series of laboratory static strength tests which were preceded by the lever static strength calculations in the computing environment ANSYS Inc. Additionally, a geometry measurement of the control - system lever at CMM equipped with a laser scanner head was made to compare with the lever CAD model to assess the quality and method of conformance.

Article contains conclusions about strength of the aluminium alloy control-system levers and the possibility of their implementation in a helicopter ILX-27. Additionally, short description of the ILX-27 program will be included.

1 General Introduction

At a time, when development of aviation is at such a high level, aeronautical engineer focuses mainly on improving individual feature of already created structures and aviation parts. There are many methods to improve the properties, for example, increasing the life of the structure, the application of new materials and using new machining methods that reduce the cost of the aerospace components formation, using new types of joints - the development of adhesive technology.

In this article we will consider the application of new material for the control lever of a unmanned helicopter. For suitability new materials in aviation structures decide not only their mechanical properties but also operating properties such as fatigue strength, abrasion resistance, cracking resistance and resistance for propagation cracks, corrosion resistance (particular in stress), resistance to erosion, heat resistance, etc. A set of characteristic, that determine the strength properties and the possibility of operating the device in called a structural strength. In case we will focus on strength tests, that will replace the heavier lever made of aluminum alloy on the levers of the new magnesium alloy. On the ability to determine accurately the structural properties influences the development of research methods. The tests will check the possibility of using lighter material with less strength, but adequate for the loads occurring in the unmanned helicopter ILX -27 control system [14].

As it is known, the magnesium alloy enjoyed a great deal of interest in the aviation industry for a long time. In the 1950s, they have been used, inter alia, in experimental airplane F80C – US Air Force, and helicopter type S55 production Westland Aircraft LTD. The Greatest advantages of magnesium as a construction material is its very low density which is only 1.74 g/cm^3 (compared to the density of aluminum is 2.7 g/cm^3, titanium of 4.4 g/cm^3, steel 7.5 -7.9 g/cm^3), making it one of the lightest metals. Since the magnesium, as a pure material, does not have a high strength and plastic properties, it is necessary alloying it with other elements, such as aluminum, zinc, manganese, lithium, beryllium, silver, tin or zirconium. The most important addition to the magnesium alloys is aluminum, which significantly increases tensile strength as well as zinc and manganese. Silver increases the strength at high temperature, the addition of silicon reduces the fluidity and enhances brittleness. Impediment in the use of magnesium alloys is also the high cost of processing by plastic processing and difficult mechanical processing[2, 4, 7, 11, 13].

This paper presents an analysis of the flight test data for control system of the unmanned helicopter ILX -27, and the analysis and laboratory stand testing of ILX -27 magnesium alloy control system lever for up to 100 hours of unmanned helicopter flight.

2 ILX-27 Fight Tests Data Analysis

The unmanned ILX-27 helicopter is a new construction designed at the Institute of Aviation in cooperation with the Air Force Institute of Technology (ITWL) and the Military Aviation Works No. 1 in Łódź (WZL-1) [6, 10]. The goal of the project was to execute ground and flight tests of the technology demonstrator, performed on an airfield proving ground.

The ILX-27 is a classic helicopter construction with a single, three blade main rotor, a ducted fan tail and the piston engine. Unique features of this construction include: fully autonomous flight mode with start and landing, long-distance communication protocol, reconfigurable fuselage structure, 5G crash-landing gear, hi-tech composite blade manufacture method and dimensions, that allow transport in a standard ship container.

Figure 1: ILX-27 in hover mode

During tests of the ILX-27, a large amount of data was collected. ILX-27 has sophisticated control and measurement system, which was essential in order to finish this project with success. Because amount of the data collected in flight is very large, the measure system is equipped with big storage memory. Helicopter measurement system was based on wide range of analogue, digital, strain and accelerometer modules. Main flight data recorder and critical data analyzer is mounted on the ILX-27 and ground station is used only for visualization of specified data, which determine test duration and abort procedures. Because almost all helicopters performance are determined by rotor, data synchronization is critical in order to get reliable results and correct answers for issues concerning helicopters, like resonances, construction fatigues, flight safety and performances.

Until today both prototypes have several hundred hours of ground tests and several dozen hours in the air. Data collected during those tests is very rich and still used in work.

Control systems of the ILX-27 are very complex and had to be checked very carefully. First of all every actuator was tested separately to check, if there are any differences in specification between those actuators. After those tests all system of actuators was checked in order to get information about whole system including power management and software. At the end ground test were performed with engine running and rest systems activated. After ground tests of control system on helicopter was completed, the ILX-27 was approved for in-flight tests on proving ground.

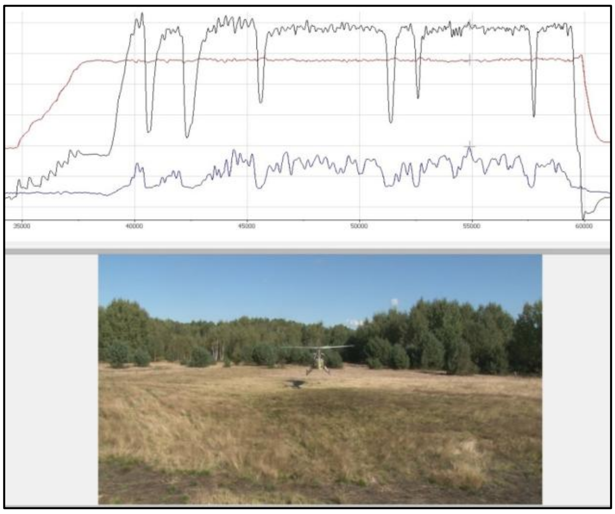


Figure 2: Data synchronization – flight parameters and video

Thanks to that, it was possible to evaluate stresses of selected critical parts, that where measured in real, operational conditions. One of those parts is the control-system lever. It is positioned between the swash plate and the actuator. The collected data includes forces and their frequencies for this part (Fig. 3), which was used to determine a fatigue-test program for the lever made from the new material. Additionally, a safety-coefficient was defined. A first verification was equivalent to a one hundred hour-check for helicopter flight.

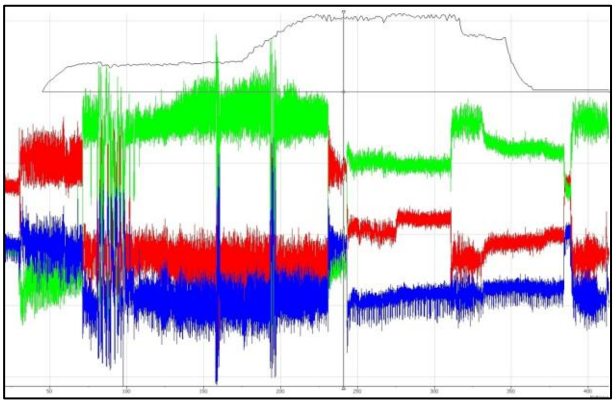


Figure 3: Forces recorded during test and main rotor speed synchronization

3 The control - system lever

Control – system levers are located between the swash plate and an actuator (Fig. 4). Therefore the levers are one of the most loaded elements of the unmanned helicopter control system.

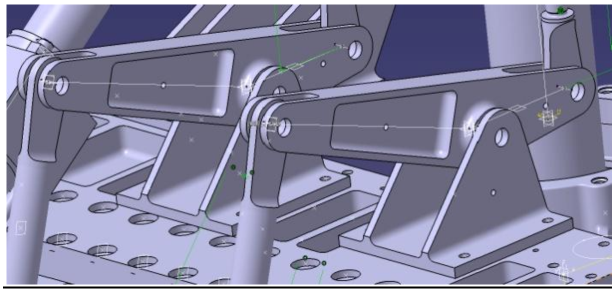


Figure 4: Control – system levers 3D model

Originally, control – system levers were designed and made of PA7 aluminium alloy. PA7 aluminium alloys are widely used in the production of parts for machines and vehicles, especially in aviation because they are capable of carrying heavy loads with relatively small weight.

The control-system lever shown in figure 5 was made of magnesium alloy in an innovative forging die process. A new method of die forging was developed at the Technical University of Lublin during the project "Modern Material Technologies in Aerospace Industry".

Figure 5: AZ31 magnesium alloy control – system lever

In aerospace engineering lightweight construction parts are very important. Through the use of magnesium whose density is 1.74 [Mg/m^3] the reduction of product mass by 30% is achieved, compared to the previously used aluminium alloys.

The weight of a lever made of PA7 aluminium alloy is approximately 321 [g], while the weight of the AZ31 magnesium alloy lever is around 35% lower and is 207 [g]. The most common magnesium alloys are Mg-Zn-Al alloys (we distinguish three alloys AZ 31, AZ 61, AZ 80), which are plastically worked by extrusion and forging methods. The Mg-Zn-Al alloy was chosen as the construction material because of its properties (Tab. 1). The magnesium alloy AZ31 is wieldable and perfectly suitable for rolling, stamping and extrusion [3, 6, 8, 15, 16].

Table 1: AZ 31 alloys properties

Alloy		Al3.0Zn1.0Mn0.3
ASTM		AZ 31
Chemical composition, % of mass	Al	2.5– 3.5
	Zn	0.7– 1.3
	Mn	0.2– 1.0
	Cu	0.05
$R_{0.2}$, MPa		150
R_m, MPa		230
A, %		8

4 Research methodology

The main test were fatigue tests of the control-system lever, which were performed on a test stand dedicated for this purpose. Fatigue tests had to give an answer about the strength of the control system lever for up to 100 hours of flight for ILX -27 unmanned helicopter. Before proceeding to fatigue testing we conducted a series of tests including geometry verification, static strength calculations using the computing environment ANSYS and static strength tests.

The geometry of the levers was verified to confirm the accuracy of the innovative die forging process of the levers. For this purpose reverse engineering was used. Measurement was made using the CMM with a laser scanner head with an accuracy from 0.001 mm. Subsequently control system lever CAD model was compared with lever model obtained from measurements at CMM. Summarizing the finished product is in places barely larger than a the CAD model. At the same time holes and mounting surfaces comply with the established tolerances.

Next step was to check the behaviour of the lever during load related with the flight of an unmanned helicopter ILX -27. In this aim static strength calculations were performed using the computing environment ANSYS (Fig.6).

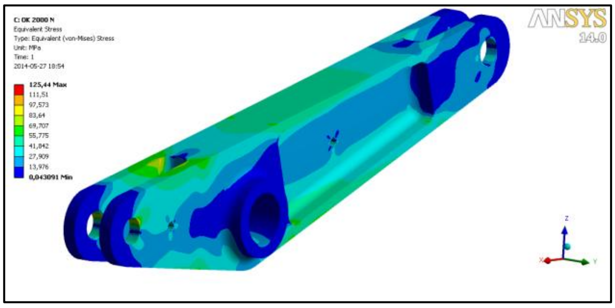


Figure 6: The reduced stresses of the lever

According to the FEM simulation the control-system lever operates in the elastic deformation and the point stress concentrations caused by the notch effect, do not exceeding yield strength or ultimate tensile strength of the material for the assumed magnesium alloy AZ-31.

The static strength tests were also made for the test object to verified and confirm with FEM calculations. Prior tests on the test stand control-system lever was prepared in accordance with the technical documentation and mounting instructions for unmanned helicopter ILX -27. Additionally electrical resistance strain gauges were installed to verify the strength and stresses at selected points of lever.

Fatigue tests were carried out simultaneously for two system - control levers, which was prepared in accordance with the technical documentation and mounting instructions for test stand. Test stand has been prepared in such manner, that best reflect the conditions during the flight of unmanned ILX-27 helicopter [1, 5, 12].

5 Control - system levers fatigue test

For the purpose of fatigue tests a test stand was developed. This test stand is able to perform tests in compliance with the specifications set by the flight conditions that the helicopter is subjected to during flight operations. Such tests encompass three parts i.e. fatigue tests, load force simulation and force measurement.

Fatigue tests, that are performed by an electrical engine, that gives the possibility to perform fatigue cycles in the range of 15 to 2000 cycles per minute.

Load forces simulation that is carried out by a compression spring system, that can simulate forces in the range of 0 to 8000N.

Load forces measurement that is carried out by a tensometric system applied directly on the testing element. Installation location was selected based on FEM strength calculations. Installation points correspond to the places with maximum stress.

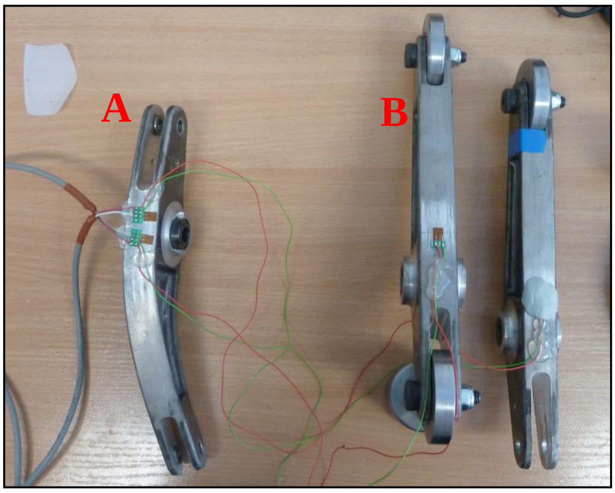


Figure 4: Lever with sensors - strain gages (B) and compensation strain gauges (A)

The strain gage measures the deformation as a change in electrical resistance, which is a measure of the strain and consequently forces. A load cell usually is composed of one, two or four strain gauges in a Wheatstone bridge configuration (quarter, half or bridge full). Most common is full and half bridge because of the best temperature compensation, the most accurate indication and obtaining maximum sensitivity. Temperature compensation is provided by the use of compensation strain gages installed on the same material. In this case we used half bridge (Fig. 7). The tests produce information concerning the mechanical wear of the magnesium alloy lever, such as might occur if used in a helicopter during flight evolutions.

The test data is acquired and presented in real time by an acquisition system that consists of a National Instruments measuring card and, a measuring application made in LabView environment that runs on a PC.

Fatigue tests were carried out simultaneously for two system - control levers, which was prepared in accordance with the technical documentation and mounting instructions for test stand. Test stand has been prepared in such manner to best reflect the conditions during the flight of unmanned ILX-27 helicopter.

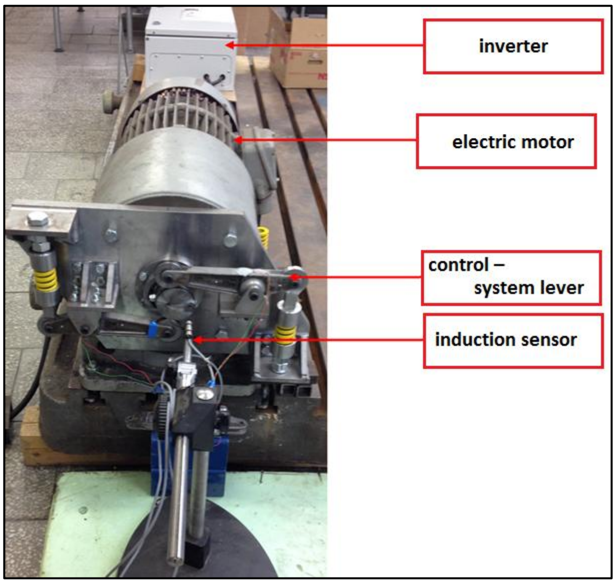


Figure 5: Fatigue test stand

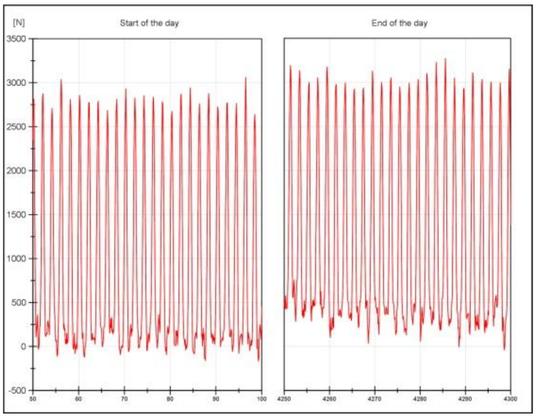
Tests were prepared for up to 100 hours of flight of the unmanned helicopter ILX -27. Selected sinusoidal cycle of stress variables in the range specified in Table No. 2.

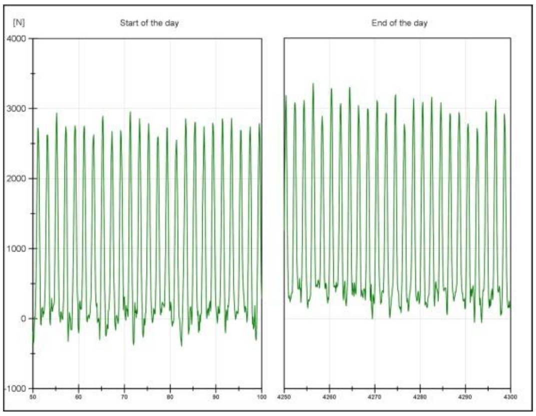
Table 2: Cycle specification

F_{min}, N	F_{max}, N	Frequency, Hz
0	3000	1

The strength and frequency of the cycles, were selected according to data from the flight test of an unmanned helicopter, specifying forces acting in the control system during horizontal flight. Tests were carried out an average 6 hours and 15 minutes a day and sustained 16 days. During 100 hours 360’000 cycles were carried out.

The graphs of shown on figure 9 represent respectively tests results from first day of tests and last day of tests.

a) 



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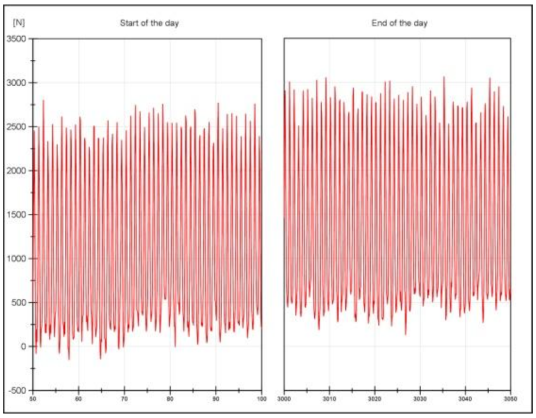

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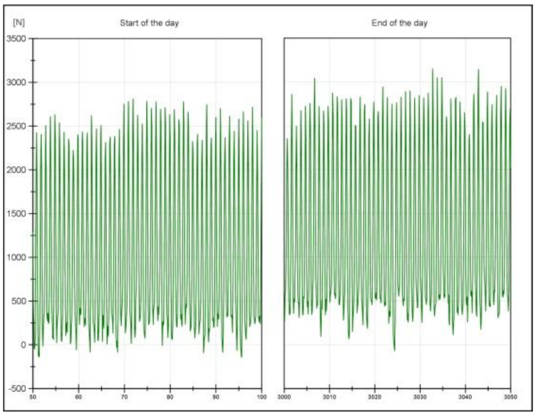

d)

Figure 6: The charts show the results of tests, a) start testing for t0; b) start testing for t1; c) end testing for t0; d) end testing for t1

6 Conclusion

To sum up, the unmanned ILX-27 helicopter designed in the Institute of Aviation is currently undergoing modification consisting of applying new materials and technologies that were not planned in the first design phase. Replacing the aluminum levers for magnesium alloy is one of the steps to reduce the weight of the helicopter by introducing new materials.

Tests of the lever have shown, that it is possible to use lighter materials than aluminum alloy to provide sufficient strength properties while reducing the overall mass of the object. Analysis of the available materials used in aerospace engineering allowed the selection of the best kind of magnesium alloy. All test which were made and indications of strain gauges proved, that replacing aluminum lever for magnesium alloy is possible without adversely affecting the strength of the control system. Despite lower structural properties, which has magnesium alloy AZ31, it is sufficient in the above-mentioned application. During the fatigue tests lever behavior have been checked after 100 hours of simulated flight of an unmanned helicopter ILX -27. The test time was adapted to the maximum time in which lever can work without any maintenance. Static strength tests have shown, that destructive force verified during the test cannot occur on the lever of the control system while flying a helicopter. Tests which were carried out, allow us to conclude, that the helicopter weight optimization through the use of new material on the control lever is correct.

Resistive strain gauge methods in this case were the optimal measurement method, which gave the opportunity to check the level of strain in real time but it requires the development of an appropriate protection system of strain gauges and levers surfaces against corrosion. This kind of protection is necessary when we will perform in-flight tests.

The prepared test stand represented an adequate load system, it allowed to simulate real loads on lever and thereby testing new material under loads occurring on the helicopter in the control system.

References

[1] Abdullah M.F., Abdullah S., et al., Fatigue life of the magnesium alloy AZ31B under specific spectrum loading, *Materials Science, Characterization & Testing*, Vol. 58 Iss. 3, pp. 200-205, 2016

[2] Bartnicki J., Pater Z., Gontarz A., Tomczak J., Innovative metal forming technologies, *Journal of Machine Engineering*, pp. 5-17, 2014

[3] Bernaczek J., Śliwa R., Budzik G., Kudasik T., Badania modelowe dźwigni układu sterowania śmigłowca, *Mechanik*, No 12, pp. 9-12, 2015
[4] Bulzak T., Tomczak J. i Pater Z., Analiza numeryczna walcowania wzdłużnego przedkuwki dźwigni ze stopu magnezu AZ31, *Rudy i Metale Nieżelazne*, No 11, pp. 748-754, 2012
[5] Chen G., Lu LT., et al., Ratcheting and low-cycle fatigue characterizations of extruded AZ31B Mg alloy with and without corrosive environment, *International Journal of Fatigue*, Vol. 80, pp. 364-371, 2015
[6] Cyganek Z., Tkocz M., The effect of AZ31 alloy flow stress description on the accuracy of forward extrusion FE simulation results, *Archives of Metallurgy and Materials*, Issue 1, pp. 199-204, 2012
[7] Dziubińska A., Gontarz A., A new method for producing magnesium alloy twin-rib aircraft brackets, *Aircraft engineering and aerospace technology*, No 2, Vol. 87, 180-188, 2015
[8] Feng F., Huang S., Meng Z., Hu J., Lei Y., Zhou M., Wu D., Yang Z., Experimental study on tensile property of AZ31B magnesium alloy at different high strain rates and temperatures, *Materials & Design*, Vol. 57, pp. 10-20, 2014
[9] Guła P., Bezzałogowy śmigłowiec – robot do zadań specjalnych, *Prace Instytutu Lotnictwa*, No 219, pp. 189-193, 2011
[10] Guła P., Gorecki T., Projekt, badania i wykonanie polskiego bezzałogowego śmigłowca ILX-27, *Prace Instytutu Lotnictwa*, No 232, pp. 39-49, 2013
[11] Hadasik E. i Kuc D., Obróbka plastyczna stopów magnezu, *Obróbka Plastyczna Metali*, tom XXIV, No 2, pp. 131-146, 2013
[12] Jia Y., Bai Y., Experimental study on the mechanical properties of AZ31B-H24 magnesium alloy sheets under various loading conditions, *International Journal of Fracture*, Vol. 197, Issue 1, 25-48, 2016
[13] Mrugała A., Ostachowski P., Łagoda M., Kuc D., Kształtowanie elementów konstrukcyjnych dla lotnictwa ze stopów lekkich metodą wyciskania na zimno w złożonym stanie odkształcenia, *Prace Naukowe, Mechanika*, Vol. 267, pp. 79-85, 2015
[14] Ostrovsky I., Henn Y., (2007), Present state and future of magnesium application in aerospace industry, *International Conference "New Challenges in Aeronautics"*, Moscow, 2007
[15] Śliwa R., Bernaczek J., Budzik G., Kudasik T., Badania modelowe w procesie projektowania i wdrażania do produkcji odkuwek dźwigni układu sterowania śmigłowca, *Rudy i Metale Nieżelazne*, No 11, pp. 619-624, 2015
[16] Xu S., Ren G., Jing C., Zhao Z., Sun K., Three-dimensional Numerical Simulation and Experimental study of Severe Plastic Deformation of AZ31 Magnesium Alloy, *Mechanical and Aerospace Engineering*, pp. 3371-3375, 2012

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Contact Author Email Address

mailto: malgorzata.wojtas@ilot.edu.pl

mailto: agnieszka.sobieszek@ilot.edu.pl

mailto: lukasz.czajkowski@ilot.edu.pl

mailto: rafal.zurawski@ilot.edu.pl