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DESIGN AND IMPLEMENTATION OF ENGINE TEST DEVICE FOR THE M601 ENGINE

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Abstract

The aim of this article is to create a proposal and documents for the implementation phase of the engine test device for the Walter M601 engine, which after implementation will serve as a teaching and research aid for researching new alternative fuels, testing different variants of propellers and others. As part of our work, we are dedicated to the development of two entire future test segments of device, namely the test stand and the design of the monitoring and regulation part, where we use the original devices, manufactured in compliance with LUN, which was directly designed in the past for the M601 engine and its installation in the L-410 Turbolet aircraft. The design of the test stand will include a 3D design and documentation. The monitoring part will consist of the design of the monitoring panel, which will contain selected engine indicators and LUN sensors, which will be used from the defined solutions of specific requirements and the design of electrical wiring and power sources and modules for the operation of the monitoring and regulation part.

Keywords

aircraft engines, aircraft engine testing, engine monitoring, engine regulation

1. INTRODUCTION

The aim of development was to design and prepare an initial version of documentation for the implementation of equipment for static and ground testing of the Walter M601 aircraft turboprop engine. The specific goal is to create a test stand and an engine monitoring and regulation system. The engine test facility for the M601 engine is intended for future use by the Department of Aviation of the University of Žilina . In the future, the engine test facility will form a teaching and research aid, namely for research into for example alternative fuels, testing of various propeller variants and various others. The implementation of the design of a specific test device for the M601 engine is created on the basis of technical documents and specifications and the implementation document is created using software tools Autodesk Inventor and Microsoft Visio.

2. WORK METHODOLOGY

2.1. Outputs of article

The outputs of the work will include 3D design, documentation created in mentioned software tools. The monitoring part will consist of the design of the control station, which will contain selected motor indicator devices of the LUN series, as well as the design of the connection of the LUN motor sensors, which will be used from the defined solutions of specific requirements and the design of electrical cabling and power sources and modules for the functioning of the monitoring and regulation part. The proposal also deals with the ignition and starting system.

2.2. Archival form of data collection

2.2.1. Method of observation

We used the observation method in the design of two units of the test device. The first unit was a test stand, where we took in consideration existing solutions of motor stands for the M601 engine, which are used, for example, in maintenance or laboratory conditions. We also effectively used the observation method during browsing of Maintenance and Installation documentation, especially the Maintenance Manual of the M601 engines installed in the L-410 aircraft. Analyzing these materials using the observation method was very helpful for creation a realistic idea about used technology of used devices for control, monitoring and another modules exclusively designed for M601 engine.

2.2.2. Analysis

Based on collected information, we tried to select and apply the best practices to our solution and at the same time not to use solutions that seemed inappropriate to us. Based on analyzed information, a technical solution was created, which is in our opinion the best possible. In terms of instruments, we were convinced that the use of original LUN instruments is the most "tailor-made" solution for the M601 engine, because the instrument ranges are designed for parameters that exactly occur during the M601 standart operation. Also, the physical application of the sensors is fully compatible with the M601 engine. In this case, complications could arise with the electrical supply of these devices mainly due to some specific devices, however, after analyzing the available electrical sources on the market, we can declare that thanks to the available solutions, the implementation of the power supply is also feasible with relatively high energy efficiency.

2.2.3. <u>Synthesis</u>

Chronologically, We put the solutions obtained during the method of observation and analysis into one for both units, which created a unified concept and discovered mutual influences of the units on each other and thanks to it the possible complications, which were solved within the framework of constructing both units as a unified device.

2.2.4. <u>Development with software tools</u>

For visualization and preparation of technical documentation, it is appropriate to use software tools which are available on market. We could divide them according to the display into: 2D and 3D.

It is convenient to use 3D tools for engineering construction of parts, assemblies, and the like, in this case for the design of a test stand. The most suitable software tool for this design and the one we used is Autodesk Inventor. The Inventor program allows us also to create drawings from 3D models.

Another used 3D modeling "tool" is the SketchUp program, which is generally designed for tasks solved by architects, especially in interior design field, however due to our experience with both above-mentioned software tools, we decided that SketchUp software is more suitable for the 3D model of the control stand, mainly due to the design and structural differences compared to the test stand.

2D tools are suitable for creating drawings and documentation such as electrical diagrams or for visualizing functional contexts. Here we consider it appropriate to use tools such as Microsoft Visio and AutoCAD, where both software are used in practice for the above-mentioned activities.

Visio is more suitable for drawings of functional relationships, layout of modules in a rack or a drawing of the location of devices on a monitoring panel. AutoCAD is more suitable for monochrome display such as electrical diagrams or component drawings. From our point of view, we would say that Visio is more suitable for documentation created for a more layman's view, for example also for the creation of documents such as system descriptions, maintenance or assembly manuals, and AutoCAD is more suitable for implementation drawings, where the documentation will be used mainly by professionals.

Considering the future purpose of the test device, we agreed about that it is more appropriate to use the Microsoft Visio software.

3. TEST STAND AND ACCESSORIES

3.1. Test stand

During designing the test stand, we determined that the first step which is requiered shall be the design of the engine mounting itself. For this part of the stand, while gathering information, we found out that there are anchor points on the engine to attach the engine itself to the aircraft, which were designed to be attached to a 60cm diameter ring made of steel tubes. Such a ring, based on the location of the anchoring points, was used in addition to the L-410 aircraft also in test or laboratory stands for the M601 engine, and therefore basically, in the design of this component, there were not many options to implement this specific attachment in a different way than with a similar ring.

To attach the ring to the stand itself on the bottom side, two welded steel plates with a thickness of 5 mm and a rectangular shape with a size of 280x100 mm will be used, which will form a monolith with the ring. Holes with a diameter of 10 mm will be drilled in each plate. We chose the spacing of the holes at 150 mm, which will be intended for the screws connecting the body of the ring to the log profiles forming the stand. During the manufacture of the ring, a cut is made in the ring at the location of each plate. A plate is placed between the two parts divided by the cut, and a weld joint is formed on each side of the plate with the cut surfaces of the ring using MIG technology.

On the upper side of the ring, the ring will be fixed to the stand by means of a pair of sleeve fixing elements, each consisting of a top and a bottom part. The lower part of the sleeves forms part of the upper horizontal beams, and the upper part forms a separate element, which will be connected to the lower part by means of a pair of M10 screws and nuts, which, after screwing, will create a sufficient compression of the upper and lower parts, so that the surfaces of the ring and the bearing surfaces of the sleeve fastening elements they press sufficiently and secure the ring. The spacing of the holes for screw connections is 60 mm.

During the development of the test stand, there was a decision that the test stand should also allow the measurement of the generated thrust in a certain way, for example in the future when testing different types of propellers. In order for this idea to be realized, the separate stand and especially the motor cannot be fixed firmly, but the engine has to have freedom of movement in the longitudinal direction. Based on knowledge and experience, we decided to use a linear bearing, which on the one hand will create a solid mechanical connection between the separate stand and the base, but at the same time we will achieve freedom in a certain limited range, which could be fully sufficient for the needs of the mentioned measurement.

However, due to the size and weight, we discovered during development that the use of linear bearings is not suitable, as they are more suitable for applications with smaller loads, especially weight.

A suitable solution for the required specification is the use of so-called linear guides, sometimes referred to as carriage guides. These linear guides are basically developed for the use of higher heavy loads, mainly because the contact surfaces on which they move have an order of magnitude larger total area and thus the total pressure load is lower.

For a specific implementation, we decided to use linear guides from the manufacturer Fisatech, where we decided to use the SGL45HTE type guide block. The use of this particular type was conditioned by the fact that only SGL series from this manufacturer is available with lengths over 1000 mm. The second reason is that we probably have the largest contact area of the selected guide blocks, where we see a benefit in distributing the load over a large area, which has a positive impact on safety, but also on the durability of the attachment[6].

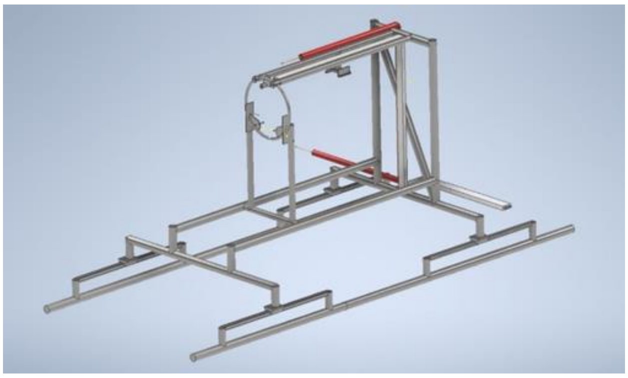


Figure 1 - Test stand with implemented guide block

The test stand is also equipped with cable duct and protected fuel line. The input for cable duct is placed in the lower left part of stand, where the bundle from control station is connected. On the right side, there is fuel line from 1000 l fuel tank which use DN19 antistatic pipe up to the place of separation, where the diameter change to 15mm steel flexible pipe which is protected by red aluminum protection pipe. The 15mm steel pipe is used because of inlet of used fuel control unit LUN 6590.05-8 FCU.

3.2. Control station

During the design, we decided that controls and control station won't be directly part of the test stand but will be implemented by a separate device that will be placed outside the test stand. From our point of view, this brings several benefits, especially from the point of view of health and safety, since the personnel who will operate the test equipment and the engine are at a safe distance from the working engine and propeller, which fundamentally reduces the potential for injury caused by indiscipline, failure of a certain part of the engine and propeller and also against the negative effects of exhaust gases, whether chemical or thermal. In addition, the negative impact of vibrations and noise, which will affect the operator's human body when the unit is working, is partially reduced.

The effects of the produced heat and vibrations also have a negative effect on electrical power supply devices, as they are not designed to work in such conditions and their service lifetime is shortened.

That's why we decided that part of the control post will also include an electrical distribution source, respectively a switchboard used to distribute and adjust electrical energy for the needs of individual devices and a battery used to start the engine. The placement of indicator and control devices in the control post is of course logically since the control post is intended for control and monitoring and therefore this equipment will be installed in this post as well.

The transmission of electrical energy and signals will be realized by a cable bundle, which will form a line between the control station and the test stand. We decided to use bundle due to require freedom of movement of engine on the test stand during the thrust measurement, so we weren´t able to use some fix solution. This bundle with predesigned length of 10 meters will transmit signals from the measuring sensors to the indicator devices in the control station and at the same time will serve to power the measuring sensors and supply control signals and power to the linear servo drives that control the displacement of these servo drives.

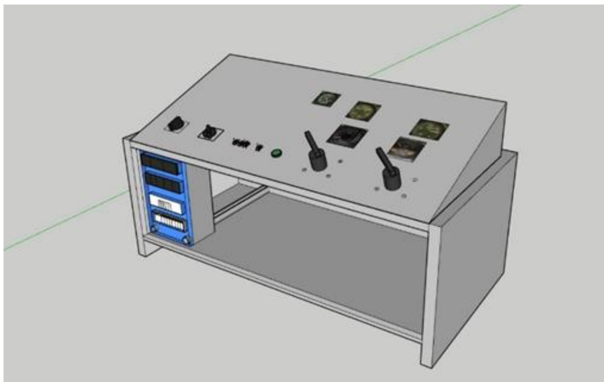


Figure 2 - Control station

3.3. Connection box

For the operation of the control and monitoring part, it was necessary to prepare and ensure its power supply. As we generally know, it is necessary to consider the specification of the devices that will be powered when designing the power supply. We are talking mainly about the type of current, whether it is direct current or alternating current, where it is also important to consider the frequency and also whether it is a harmonic or PWM type of signal. Last but not least, it is important to clarify what peak or working performance we can achieve in powered devices, based on which we have to choose the elements of the power supply system appropriately, including elements that ensure protection against overload or short circuit and of course the cross-sections of the wires through which the currents will flow.

The source of electrical energy for the test equipment will be the distribution network in the form of a single-phase 230V/50Hz power supply in the TN-S system from local distribution networks at the testing location. The supply line will be realized with a copper flexible cable H05VV-F 3Gx4, which will be connected to the distribution network via a standard plug and at the other end will be connected to the Hensel Mi 1444 switchboard with IP65 protection, which will be installed within the control station. The cores of all cables and wires mentioned in this proposal are made of copper.

At the input of the electrical circuit of the switchboard, a combined residual current device with circuit breaker, a RCD1 will be placed, which will ensure the protection of the entire control and monitoring part against short circuit and overload using the fuse part, and protection against electric shock will be provided by the residual current device. We decided to choose the residual current device mainly because of the relatively "delicate" environment in which the test stand and parts of the control and monitoring part can be placed during operation, namely: high temperature environment, humid and wet environment in combination with a metal structure, where it is not possible no way to make a double-insulated implementation.

For additional protection against short circuit and overload we implemented circuit breakers FA1-FA8 for AC input of each circuit and fuses FU1-FU8 for DC section of circuits.

As for the AC/DC sources, we chose the manufacturer Traco Power, specifically the TBL, TPC and TXH series, which are intended for industrial automation and suitable for installation in a switchboard with mounting on a DIN rail, except for the TXH series, which will be attached to the control station with steel profiles. Sources intended for mounting on a DIN rail will be placed together with safety elements in the Hensel Mi 1444 switchboard within the control station. Based on the required voltages of 12V and 28V DC, we decided to use three specific types. The 12V power supply will be provided by TBL 150-112 type with 120W power at 84% efficiency and TXH360-112 type with 360W power at 89% efficiency. We implemented the 28V power supply using a TPC 120-124, with a power of 120W and a voltage range of 24 to 28.8V. The efficiency reaches 87% [8].

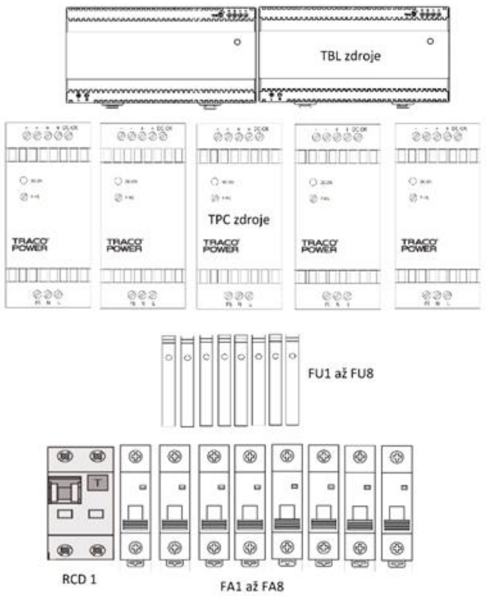


Figure 3 - Design of Connection Box

3.4. PWM regulation

Engine regulation is performed mechanically in the rear part of the engine, in the part where there is space for auxiliary aggregates, through the already mentioned complex device LUN 6590.05-8 FCU, on which the intake regulation is carried out with a mechanical tie rod. Unfortunatelly, our specimen of M601 doesn´t allow us to use any FADEC solution.

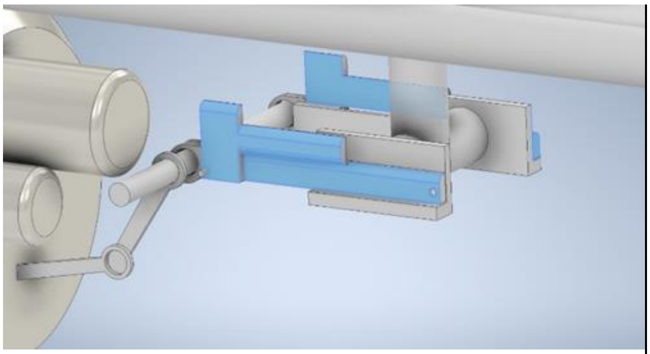
For this particular implementation, we decided that the control rod will be moved by means of a linear servo drive, which will change its extension/retraction and thus also the position of the control rod through the PWM signal. As part of the research on the servo drive market, we can find different variants of servo drive displacement regulation. This is usually either via limit switches or timers, but the position can only be set at points where the switch/time positions can be realised, the direction is set by changing the polarity of the supply and the displacement speed is fixed. In the case of PWM regulation, the advantage is that the exact shift position can be set without the need to define a specific point by a certain element, but the exact length of insertion/extraction is defined at a specific position of the rotary controller. The direction and speed can also be regulated using the rotary controller, where these quantities are defined by the direction and speed of rotation of the rotary controller. Such regulation is carried out by electronic PWM regulators, which create a pulse-width modulated signal based on the position of the rotary controller from the DC power supply.

As a PWM controller, we decided to use the so-called goBILDASERVO COMMANDER, which just provided PWM regulation for such an implementation by its design. In order to function and especially to generate a PWM signal, it is necessary to provide power in the voltage range from 5 to 15V at the terminals marked + and -, on the bottom of module. The generated PWM signal reaches the regulated device through the three-pin connector on the upper part of the regulator.

So, as a linear servo drive, we decided to use the HDLS-4-30-12V type, which is a servo drive that can be controlled by a PWM signal and has an additional 12V DC power supply to ensure the same performance and displacement force. This particular type has a maximum travel speed of 0.762 cm per second, which is one of the lowest speeds on market. We chose this variant, as we think that high precision is necessary for the regulation of the mentioned rod, and the choice of a faster servo drive would be counterproductive [15].

In order to maintain a sufficient degree of redundancy, we decided to use a pair of these servo drives to control the tie rod, where both will be mechanically connected to the tie rod, but only one will be active at the same time.

So one will be the main servo drive and the second servo drive will be a backup, referred to as back-up. The reason why we decided to duplicate this servo drive system is that if, in the case of a working engine, there was a malfunction in the main PWM control circuit, either on the electrical wiring and control, or on the servo drive itself, it would not be possible to control, or safely under safe conditions and circumstances reduce power to at least idle mode. The engine would be in this state of very limited control, controllable only by blocking the fuel supply with a valve, which would make it possible to bring the engine and equipment into a safe mode. However, apart from the safety point of view, this is also not suitable due to the long-term service lifetime and technologies of the engine, namely for turbines and shaft bearings, as when switching off in nominal or maximum mode, without prior smooth cooling in idling mode, such a sudden shutdown could mean a significant weakening of the components, respectively affecting the structure of the turbine material or significant carbon deposits on lubricated surfaces. Of course, if such a scenario occurs, it may not automatically mean its immediate damage or destruction, but it is advisable to minimize it, as it is not easy to predict when for example the structural and fatigue state of a certain component will occur.



Fiure 4 - Principial 3D model of Linear servo drive

4. CONCLUSION

We think that with the outputs of this article, we have created a guideline and a solution for a test stand that will fully serve its purpose, will be safe and reliable enough for test operation, and will be able to be comfortably operated by an operator who has lay knowledge of electrical engineering and at the same time, it will offer sufficient modularity for all possible future experiments and modifications. We are satisfied with the design of the test stand and we think that my design represents a mechanically solid solution that also allows the desired measurement of the generated thrust due to the implementation of linear guides. Regarding the storage and supply of fuel, in our opinion, it was really impossible to find another better solution for the given conditions. The issue of supplying not only fuel but also electrical signals resulted from the need for physical freedom of the engine and the observance of certain safe distances from the working engine, and therefore it was necessary to use a flexible hose of 10 m length and also a cable harness of the same length, which are not additionally protected in any way due to mechanical flexibility. We tried to protect the fuel pipes and cables, at least in the most critical place, near the engine, on the structures from negative influences as much as possible. We tried to design the control station intuitively and ergonomically and from our subjective point of view this declared solution is correct. The advantage of the design of the control post is also that the question of the location of the distribution switchboard for electronic systems was solved relatively easily. We are extremely satisfied with the used AC/DC sources, which have very compact dimensions, very good operational and electrical parameters for the given implementation, including efficiency, and almost all of them could be placed in a common switchboard. During the design, we tried to make the electrical part as simple as possible for maintenance, not only for its implementation, but also for the price and the possibility of supplying spare parts, and therefore in the end we decided not to use the technology of IGBT transistors in the starting system for switching, since the auxiliary electronics, which would solve the regulation of this transistor would be too unnecessarily complicated, especially for maintenance. However, the truth remains that the used relay solution is also quite complicated, which was mainly caused by the very specific switching parameters of the coils and it is energetically extremely disadvantageous due to the need to use a source with a power of 300W, but its activation and function will take a few seconds, so the energy efficiency is negligible, which refers to the consumption of electricity and the advantage is that the circuit consists of really simple and accessible elements, without the need for special tools and possibly even a layman can handle the repairs. It was quite difficult to solve the motor regulation, which for a specific piece of the M601 motor can only be solved mechanically via the LUN 6590.05-8 FCU module, and therefore it was necessary to come up with a mechanical solution. That's why we decided to use linear servo drives, which thanks to PWM regulation allows us to control the shift very precisely and intuitively. Here, we also tried to ensure sufficient redundancy of the regulatory and execution elements of the regulation to ensure sufficient safety. Within the given conditions, we think that is the only possible solution and we really cannot imagine any other more suitable solution with the used LUN 6590.05-8 FCU control module. For monitoring engine parameters, we decided to use LUN devices, which we found suitable, especially with regard to the interval of the displayed parameters, which are precisely within the operating parameters of the engine and at the same time are compatible with LUN sensors, for which holes/mounting places are also created on the engine . It was also relatively easy to design a power supply system for these devices through AC/DC sources. The last system solved was the ignition system. However, after inspecting the engine, it was obvious that there was no point in developing a solution other than using the existing ignition system, where it was only necessary to supply a source and cabling for the 28V DC power supply. In conclusion, we would like to add that this proposal represents the initial or basic version of the test stand, however, in our opinion, this proposal has a wide variety of modifications for selected testing and great possibilities for improvement in the future, at least within the electrical part. Namely, we thought of modern technologies such as FADEC for regulation with newly designed fuel control unit, or the use of digital recording devices, for example using cloud solutions for long-term monitoring and many, many others.

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