A SMALL TURBOJET ENGINE MPM-20 WITH VARIABLE EXHAUST NOZZLE

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The aim of this thesis is to describe the jet engine MPM-20 with a variable nozzle exit, as a system with two degrees of freedom. The paper describes the development and current status of MPM-20 engine in the test engine. In the following analysis, in describing the effect of changing the nozzle exit section to run the engine with regard to the planned structural remodeling MPM20 engine. The core work is to address proposals for changes in the output control section. In the last part of this work is described showing the effect on the measurement speed due to changes in engine output variabile exhaust nozzle section.

K e y w o r d s. MPM-20, variabile exhaust nozzle, exit face nozzle, LTKM, servo

1 INTRODUCTION

The object of the investigation and resolution of this work, is the air turbo trigger TS-20, modified for small jet engine MPM-20 and is located in a laboratory at the Faculty of Aviation Technical University in Košice. The engine, despite its size, different from other major engines of similar design. The engine of this class is suitable for laboratory experiments, because of its size and uncomplicated and the economic availability.

Plans to renovate the engine MPM-20 motor with adjustable output nozzle created a requirement for design control and review of the outlet nozzle of behavior to the use of such a system, which will be expanded to the second degree of freedom, whereas the first stage deals with the supply of fuel into the main combustion chamber.

The purpose of this thesis was to design the drive to change the outlet nozzle exit section and perform mathematical model that shows what effect a change in the output section MPM-20.

Controlling the nozzle exit area A_5 is most often used to:

- Shortening the time required to start and the engine,
- To short the period of acceleration at maximum speed,
- To achieve the lowest fuel consumption
- To obtain maximum thrust.

2 SINGLEJET AND SINGLEROTOR AIR JET ENGINE WITH VARIABLE NOZZLE AS A CONTROLLED OBJECT

The purpose of the system output of air jet engine is to exhaust gases from the engine into the atmosphere, to guide them in the desired direction and simultaneously converts thermal energy and pressure of gas at the gas kinetic energy. The output tract thus obtained thrust force F that drives the aircraft forward.

Air jet engine in many cases uses a variable nozzle exit, which allows you to change the output nozzle critical section A_5.

Change of the section A_5 size affects the total gas pressure in the turbine p_{4C}. In terms of joint work of the engine and turbo outlet nozzle that at a magnification of section A_5, p_{4C} gas pressure decreases as the turbine. The total expansion pressure drop in gas turbine π_{TC} applies:

$$\pi_{TC} = \frac{p_{3c}}{p_{4c}},$$

where: p_{3C} - total gas pressure before the turbine,
p_{4C} - total pressure of the gas behind the turbine.

Change A_5 affects the value of p_{4C}, which compared to p_{3C} value changes significantly. This has the effect of maximizing up A_5 the π_{TC} turbine pressure drop increases and vice minimize A_5 reducing the pressure drop across the turbine π_{TC}. Work of turbine W_{TC} singlejet, singleshaft aviation turbo engine determined by:

$$W_{Tc} = c_{p,pl} \cdot T_{3c}\left[1 - \frac{1}{\pi_{TC}^{\frac{\kappa'-1}{\kappa'}}}\right] \cdot \eta_{TC},$$

Where: $c_{p,pl}$ - specific heat capacity of gas at constant tension,
T_{3c} - total temperature of the gas before gas turbine,
κ '- poison`s gas constant,
η_{Tc} - total turbine efficiency.

According to the relation specific, W_{TC} turbine work is directly related to π_{TC}, and that depends on the A_5. This relationship explains the impact of controlling the nozzle exit section of the engine run. Change of W_{TC} has an impact on the value of the parameters of thermal circulation of engine engine as thrust F and specific consumption c_m.

The steady operation of the engine must be acomplished the condition:

$$W_{Tc} \cdot \eta_m = W_{Kc},$$

Where: W_{TC} - total turbine work,
η_m - engine mechanical efficiency,
W_{Kc} - total compressor work.

The above conditions shows that:
- Engine will accelerate if the total work of the turbine W_{TC} increases:

$$W_{Tc} \cdot \eta_m > W_{Kc},$$

- The engine will decelerate if the total work of the turbine W_{TC} reduces:

$$W_{Tc} \cdot \eta_m < W_{Kc},$$

The introduction of variable cross section A_5 is obtained in addition to the fuel mass flow Q_p into the main combustion chamber further regulatory parameter. Air jet engine becomes the object of regulation with two degrees of freedom.

3 ANALYSIS OF CONTROL THE OUTLET NOZZLES WITH VARIABLE GEOMETRY

For design of control, I came out from the basic entry requirements:
- The force required to control min. - 40 kg
- Railway leverage needed to change the section of the A5min to A5max - 40 mm
- Time to change cross - 1sec.

Fig. 1 Output control system for MPM20 engine with variable output section

The force needed to control the is not the exact value, but only estimated, because, there is no technical documentation for the output system. In consultation with the leader of this thesis, gave me two available engines, for which I could design the control of the outlet nozzle. As the first, is electric motor, which output movement is a sliding movement and his name is MP-100M. As second option, with which I can work with, I was given HV DS8921 servo motor.

3.1 Control using servo HV DS8921

Servo motor HV DS8921 is actually a miniature electric motor with gearbox.
Parameters:
- Torque up to 36.5 Nm kg.cm = 3.569 at 8.5 V,
- Maximum speed of rotation of 60 ° / 0.13sec.,
- Supply voltage range U = 6.0 V to 8.5 V.

Fig. 2 Servo HV DS8921

On the positive side of this servo is that it provides the possibility of positioning the rotary shaft, and the output shaft position feedback member issensed (usually a potentiometer) that transmitslocation data back to the builted-in controller n in servo. The electronics ensures the control ofspeed, direction of rotation of motor.

Desired location of output shaft is awarded to the control electronics as a pulse as width modulated signal as also known as PWM (pulse-width modulated) signal Fig 3.

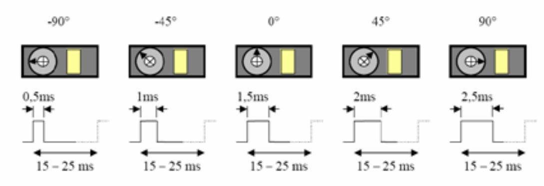

Fig. 3 Adjusting of Servo shaft position

In the design of the controlling the outlet nozzle by servo i take into consideration it`s outputs to requirements that were imposed by output deck.

After several calculations, I excluded control servo by lever because the output of the multiplier lever mechanism to control the outlet nozzle I was always wrongand the ratio of force displacement. When sufficient deflection, there was very little force.

After further reflection it occurred to me to fit servo, with small cog gear, which will drive the large cog gear. Large cog gear would be directly linked to the deck through the output rod.

During the design of this control was preddicted, that the force required to operate systemwill output will be maximum of 20 kg.

After implementation of the calculation, I found out, that control would be realistic and I realized it.

The output shaft of the servo, was planted by small cog gear whose diameter is dp = 30 mm, the radius r1 = 15 mm.

As a second cog gear used to pitch diameter dp = 180 mm, radius r2 = 90 mm.

On this combination of gearing and gear ratio i= 6, I computed the rotation of the small cog gear by β1 = 174 °, the large sprocket is rotated by an angle β2 = 29 °.

Point of links with a large cog gear with rod is on radius r3 = 80mm. The strength of the rod would be F3 '= 259.17 N - 26.4 kg.

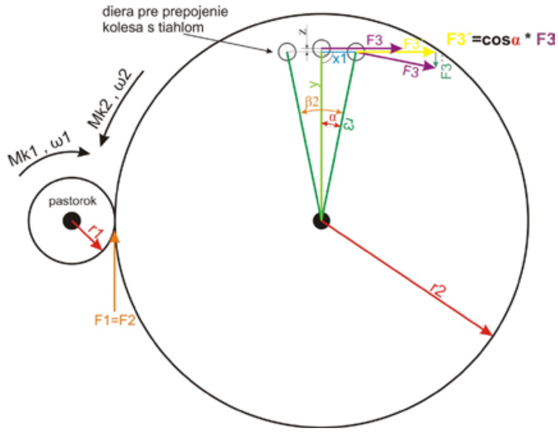

Fig. 4 Graphical outline of the calculation

From the Picture can be seen that small cog gear would its strength (whose size is determined from the torque of the servo Mk1) transferred to the large cog gear on a pitch circle. Thus F1 = F2 and it is known that:

- Mk1 = 3.569 Nm
- r1 = 15 mm

Then:

$$Mk1 = F1 \cdot r1$$

$$F1 = F2 = \frac{Mk1}{r1}$$

To find the value of F3 will apply:

$$Mk2 = Mk3$$

$$F2 \cdot r2 = F3 \cdot r3$$

$$F3 = \frac{F2 \cdot r2}{r3}$$

Using the trigonometric sinus function, we can calculate the angle α.

$$\sin \alpha = \frac{r3}{x1}$$

The angle α is only for the value of x1 which is ½ of the required movement lenght.

After obtaining the value of angle α, we can calculate the value of F3 '.

$$F3' = cos \cdot \alpha \cdot F3$$

Doubling the angle α is equal to the β2. β2 is the total angle of rotation of large cog gear required to length equal 40mm to shift lever controlling the output section A5 system.

If the angle β2 multiplying by gear ratio i=6 we get the value of the angle β1 which expresses by how large an angle will shoot small gear which is connected with the engine. Angle β1 must be less than 180 degrees, because this value is the maximum displacement of the servomotor. In this proposal is calculated the value of the angle β1 = 173.7 °.

Motor is rotating at speed of 60 °/0.13sec. then the time t required to change the nozzle exit section of the A_{5min} to A_{5max} is calculated by the formula:

$$\frac{t}{\beta 1} = \frac{0,13}{60}$$

$$t = \frac{\beta 1 \cdot 0,13}{60}$$

$$t = 0,3764\ s$$

The results of the time, deflections and force came out in the required values as i preddict, however if we consider that the force required to operate system will output a maximum of 20 kg.

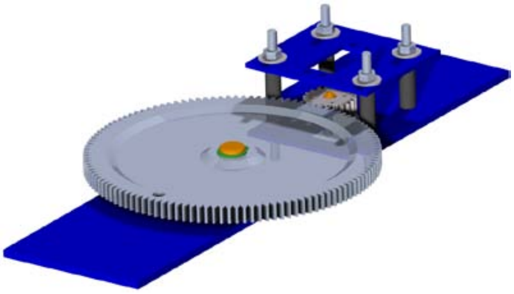

Fig. 5 Construction for the control of outlet nozzle by servo help

When you try to control the system output it was found that the power to change cross section is considerably higher and leader of this thesise increased value from 20 kg to 40 kg.

Ignorance of the necessary force to control the outlet nozzles is because to the nozzle exit (Fig. 1) is no technical documentation.

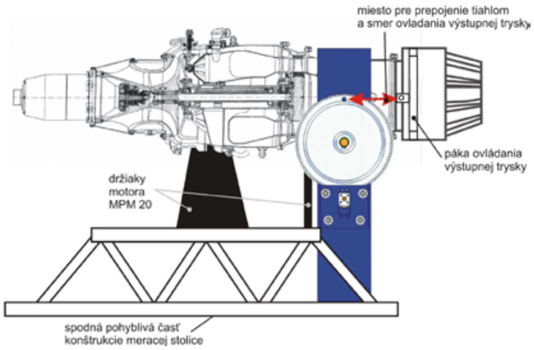

Fig. 6 Illustration of the location of the construction for controlling the output using the servo

For the use of that construction I design to use servomotor from PEGASUS labeled PA-R-340-9. The proposed servo control method has the same principle as described above servo HV DS8921.

Parameters:

- Constant torque of 10 Nm,
- Max. torque 17.5 Nm,
- Range of supply voltage U = 18 to 32 V,
- Working angle of ± 90 °,
- Rotation speed 230 ° / 1 sec.

The above calculation of F3´ in the extreme position will be 726.184 N. The total time t,needed to change the cross section from A_{5max} to A_{5min} will be 0.76 sec..

Fig. 7 Servo PA-R-340-9

The advantage of the controlling would be the conditionof the shortest duration and the possibility of continuous controlling and positioning servo at range from 0 ° to 90 ° right and left also.

The advantage of using a wheeled structure with servo is that the servo power is used in its entirety steering.

3.2 Controlling of electromotor MP-100 M

Given the electric MP-100M performs rod movement forward and backward.

Parameters:

- Namely	- 100 kg,
- Maximum	- 150 kg,
- Static	- 400 kg,
- Power supply	- U = 27 V,
- Current	- I = 2 A,
- Speed	- 2.29 to 3.1 (mm / s)
- The working stroke of	- 10-80 mm.

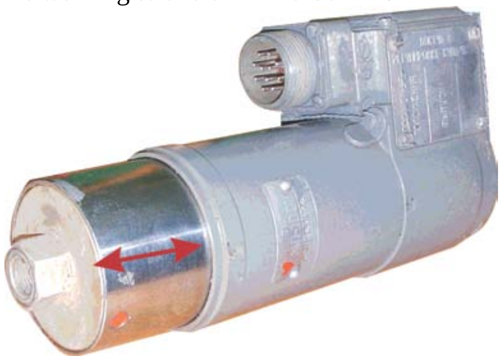

Fig. 8 Electric MP-100M

To use the MP-100M, I thought to speed up his movement by one lever. Conversion using a single lever showed that the engine does not meet the recruitments.

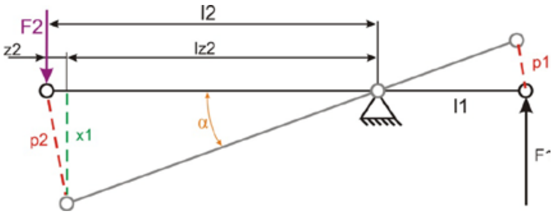

Fig. 9 Graphically outline of solutions to control the outlet nozzle bylever for MP-100M

F1 is the force of electric engine.

The calculation procedure consists of:

$$Mk1 = Mk2$$

$$F1 \cdot l1 = F2 \cdot l2$$

One variant is that levers will be long 11 = 30mm and l2 = 80 mm, then F2 = 56.25 kg, but the overall movement time will be 6.5 sec.. In this case, time and power directly dependent on each other, increases force F2 also increases the time needed to scroll.

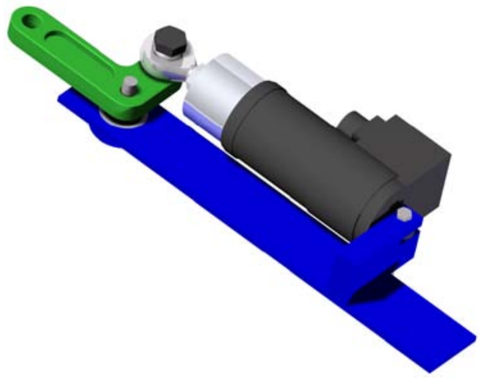

Fig. 10 Construction of controlling the output system using MP-100M and levers

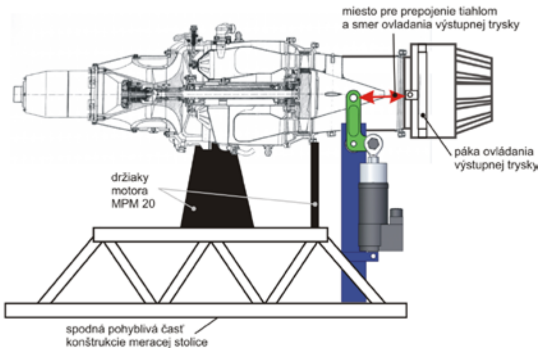

Fig. 11 Illustration of the location of the construction of the controlling system output using MP-100M and levers

4 CREATING A MATHEMATICAL MODEL OF MPM-20 ENGINE WITH ONE DEGREE OF FREEDOM AND IT`S VERIFICATION

Creating a mathematical model is based on one degree of freedom, where regulation is section of nozzle exit.

Based on the measured data in the test engine, the transient characteristic was created of Fig.12 - graph of depence of variablity of speed from change of the output section of the A_{5min} to A_{5max} at constant supply of fuel, where the x-axis represents time t, and y-axis is the rounds n. During the measurement, a change of rounds happened from n_{min} = 47,850 (rpm^{-1}), to n_{max} = 48,750(rpm^{-1}).

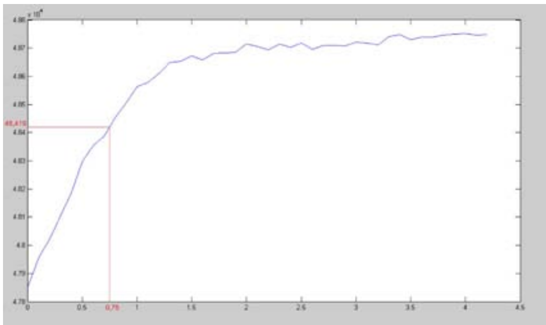

Fig. 12 The transfer characteristic of variable rounds by varying the output section of the A_{5min} to A_{5max} at constant fuel.

To determine the mathematical model of the engine MPM-20 was determined from the measured values gain of kp and time constant Tp, which characterizes the transition story of rounds.

After determining the values of Tp and kpA5 using MATLAB, I give the transition fig. 12 simulate the application through the SIMULINK block diagram in Fig. 13. The numerator is the value of kp = 0.0293, and the denominator is the value Tp = 0.75.

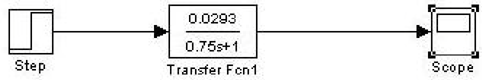

Fig. 13 Block diagram of the transmission functionality in MATLAB Simulink

The result of transient simulation plot is shown in Fig. 14, where the x-axis represents time and y axis the relative change in speed.

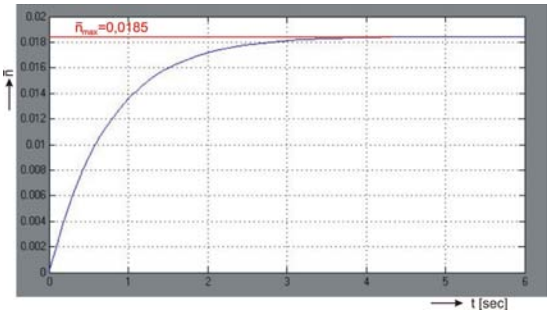

Fig. 14 The ideal transition of proportional variable rounds for sudden change of A_{5min} to A_{5max}

Consolidating the process of value nmax-0.0185 means that the rounds has been reached nmax =48750 rpm^{-1}.

4.1 Verification of the model engine MPM-20

Data of change rounds depences on the change of cross section were measured manually by controlling the nozzle exit section. Due to security was made only one measurement to reliably determine the mathematical model and for it`s verification completely is not adequate. Used output system has a bug in it`s own construction, because the influence of exposure to high temperatures is an exit gas goes to temperatured change of materials of nozzle segments, causing unwanted change in the output section, and thus increase the rounds without moving the lever. It would therefore be appropriate to obtain a more accurate mathematical model and its verification, an adaptation of the nozzle or to construct new ones.

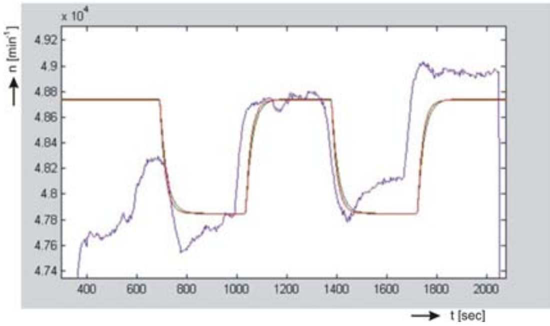

Fig. 15 Verification of the mathematical model of the engine MPM-20

At Fig. 15 we can see a comparison of simulation of transient processes of change of rounds with the measured data to the engine. The red curve is a simulation using funcion of 1st rad in Fig. 13 green curve represents the simulation using the method of gradual integration with the transfer function of 2nd order:

$$F(s) = \frac{75014}{0{,}0054s^2 + 0{,}6169s + 1}.$$

5 CONCLUSION

In thesis the design of controlling of change of cross section of the outlet nozzle, by support of different power and mechanisms that serve to the use of force and motion orientation engine to change the output section in a relatively short time. Neither of the engine which leader of the thesis gave me was not suitable for the implementation of controlling system changes the output section. For functional operation, I proposed servo engine PA-R-340-9.

After installing the system output variable nozzle output values were measured by manual controlling of lever controled the outlet nozzle and the measurement was made. We compared measured values of changes rounds of engine with value simulations. The result of simulation using the first transfer function was significantly different from the simulation using the method of gradual integration, which was used for the transfer function of second transfer. These simulations, however, had significant deviations (about 200 rpm^{-1}) from the actual measured values, mainly due to thermal change of material of outlet nozzle. The nozzle would be appropriate to modify or construct a completely new one.

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