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TRANSLATION

AUTOMATION OF LIQUID FUEL ROCKET ENGINES

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AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

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AUTOMATION OF LIQUID FUEL ROCKET ENGINES

R. Staniszewski

One of the absolute systems of liquid fuel rocket engines is the automatic control system. It has the purpose of maintaining engine operation in certain specific ranges; in addition, it assures stable operation, and when necessary it enables regulation of parameters in accordance with described program.

The automatic control system is continuously being developed and modified. If, the first types of engines had a simple, and even a primitive arrangement, modern rocket drives have predominantly developed and frequently based on electronic system amplifiers, automations and regulations. This is the result of quite frequently refined problems which are placed before automatic control systems. From the present viewpoint on, such a system should also assure work in optimum conditions, that means such conditions at which the engine works most perfectly and most economically.

It is clear therefore, that the automatic control system of a modern engine is subject not only to law of automatics but also to technical cybernetics. In view of the wide problems of this question, in this article will be discussed only certain problems pertaining to the hitherto applied automatic control systems.

Division of control systems.

There is so far no systematized part of regulation systems. This is also evident from the fact, that rocket technique is rather a young domain, and in addition much information from this field is still not published. That is why the division, brought up here, may be suggestive. However, it covers all hitherto known systems and automatic control systems of rocket engines working on liquid driving material. One of the possible variants of automatic engine regulation includes:

1) control system for engine of turbopump feeding;

2) engine control system of pressure feeding;

3) engine control system of variable thrust;

4) synchronizing systems.

All four basic types of systems differ between themselves in construction as well as in performance. The first two include all available engines of constant thrust. Inspite of all this, their automatic control systems differ also in construction. In first case, because of the application of centrifugal elements in the turbopump system, special maximum regulators or maximum rpm limiters are introduced. In case of a pressure fed engine it has no such devices, but the valve system is again quite considerably developed. Most developed are regulation systems of variable thrust engines. In this case in addition to systems, which ha a constant thrust system, there must also be systems allowing regulation of fuel and oxygen intake as well as of stabilizing complexes.

The synchronization systems placed in fourth place pertain to regulation of work of two or several engines. Their purpose is regulation of consecutive or simultaneous connection and disconnection of individual engines. Successive connection, takes place in multistage rockets, where the synchronisation system assures connection of the engine of the next degree, as soon when the engine of the previous degree stops working. Connection of subsequent engines can also take place on an aircraft driven by a series of rocket engines during the realization of jumping thrust regulation. Simultaneous connection of several engines, can in principle take place only on an aircraft during the application of rocket drive consisting of several engines. Synchronization systems are applied also then, if one engine is a multichamber one. They serve then for synchronization of work of individual chambers.

Regulation system of turbopump feed engines.

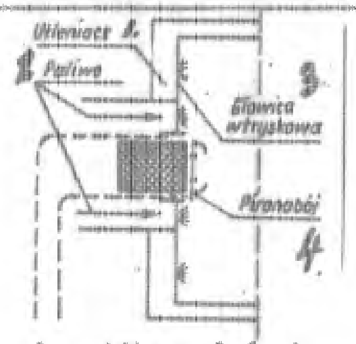
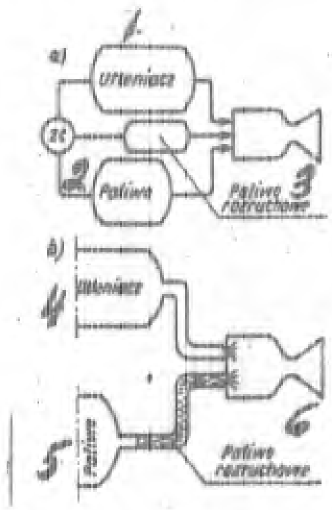
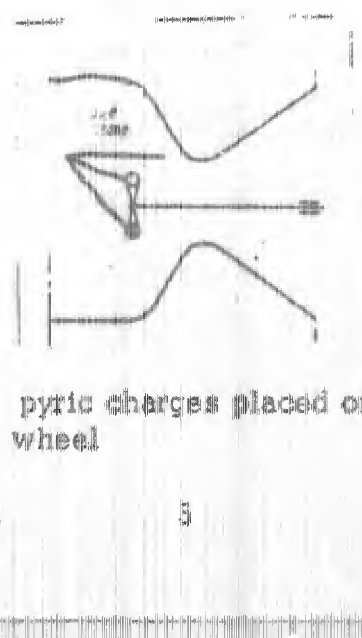
In the entire system of a rocket engine there is a liquid driving material of turbopump feeding including the following systems:

1. Starting system of engine (URS). Its purpose is synchronization of work of individual units of the engine during its starting. With the aid of electric installations is also connected the starter, which in turn drives the turbopump arrangement. An electromagnetic vlave is opened simulatenously (ZE) and the gas from the pressure tank (ZC) flows through the reductor (R) and then to the hydrogen peroxide tank (H_2O_2). The pushed out hydrogen peroxide gets to the vapor catalyst (KP) and here under the effect of calcium permanganate is decomposed into steam of a pressure of 15-30 kg/cm^2 and temperature of about 500°C. The vapor goes to the turbine and begins driving same, rotating simultaneously the pumps placed on the same shaft. When the turbine has already sufficient power- the starter is automatically disconnected. The working pumps pump fuel and oxygen into the combustion chamber of the engine.

2. Engine ignition system (UZS). Such a system exists only then, when the driving material is a not self ignition medium. For example, when we deal in petroleum and nitric acid or petroleum and hydrogen perioxide, eventually other combinations not igniting when coming in contact with surround temperature. The purpose of the UZS then is to initiate ignition in the chamber. The ignition methods applied so far together with the schemes and short descriptions are given in Table 1.

3. Stabilizing system of turbopump arrangement (USZT). When planning a turbopump system it is difficult to select the characteristics so that the pump power should always equal turbine power. The pre-

Table 1

UZS TYPE	SCHEME	BRIEF EXPLANATION OF WORKING PRINCIPLE
pironatactical ignition system	 1-oxidizer; 2-fuel; 3-injection head; 4-pyro charge	the pyro charge is placed in injection head in a special casing. It is connected with UZS through an electric installation. Prior to feeding fuel and oxidation into the combustion chamber, the electric ignition material situated in the pyro charge is ignited.
liquid fuel ignition system (a) with tank; (b) with fuel in conduits	 1-oxidizer; 2-fuel; 3-starting fuel; 4-oxidizer; 5-fuel; 6-starting fuel.	in a special small tank is situated the self igniting fuel. At the moment of starting into the chamber is fed first of all self igniting fuel and only then working fuel. Self igniting fuel is placed in a conduit between working fuel tank and combustion chamber. During the starting into the chamber goes first self ignition fuel, which upon contact with the oxygen combusts forming a gas.
outer ignition system	 pyric charges placed on wheel	on wheel introduced from the side of nozzle are placed pyric charges. Before feeding fuel and oxidizer into the chamber are ignited electric loads of these charges. The gas atmosphere created in this way is homogenized by the revolution of this equipment offering the possibility of free ignition of the working fuel. During rocket start this equipment remains. Such ignition system are applied to large engines.

dominance of turbine power causes an increase in revolutions, and the predominance of pump power a drop in revolutions, as result of which the work of the turbopump system is unstable. For this reason, it becomes necessary to stabilize the revolutions (Fig. 2).

If turbine revolutions go above the permissible revolutions, then the regulator weights cause displacement of the distributor (2) downwards. Then from conduits (a) being under hydraulic fuel pressure, the liquid will flow by conduit (c) all the way under the servo piston (4). The servo piston will be shifted upwards, thus causing an increase in flow through of hydrogen peroxide being in closed circulation. In this way, the amount of hydrogen peroxide going to the catalyst will decrease, thus the amount of steam transmitted to the turbine will decrease. As result of such action of the regulation system turbine rpms will decrease. If there would not be the so-called reverse coupling (SZ), then the sup up of hydrogen peroxide flow through would be too violent. As result of this a drop of revolutions would come not from the calculated revolutions, but much below that. Later, the regulator would cause again a rise in revolutions, and then a drop. Such fluctuations are sometimes long and have a negative effect on the operation of the turbopump system. That is why in modern regulation systems is introduced a special reverse coupling. They are for the purpose of alleviating the transfer process, as result the change over from one type to other revolutions of the turbopump system is relatively rapid, but smooth.

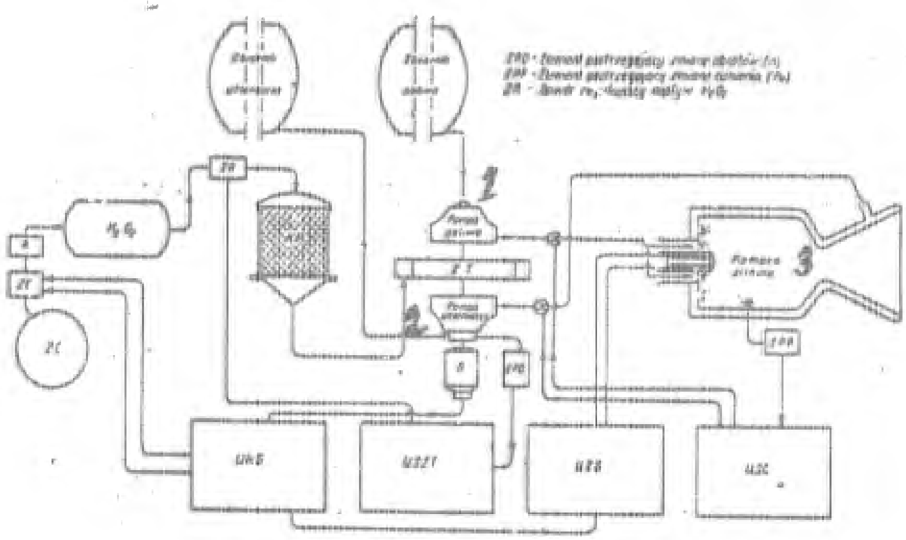


Fig. 1.

Diagram of rocket engine on liquid driving material with turbopump feeding, with designation of automatic control system. EPO-element warning about change in revolutions (n); EPP – element warning about change in pressure (P_0); ZR-valve controlling H_2O_2 flow. <u>KEY:</u> 1-fuel pump; 2-oxygen pump; 3-engine combustion chamber.

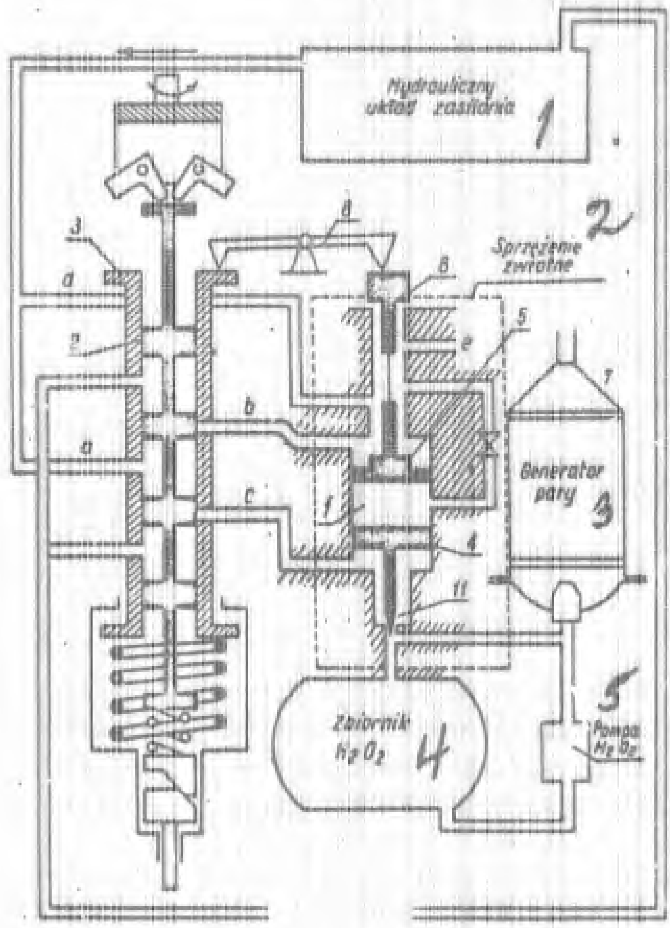


Fig. 2.
Diagram of one of the possible stabilizing systems. KEY: 1-hydraulic feeding system, 2-reverse coupling, 3-steam generator; H_2O_2 tank; H_2O_2 pump.

4. Pressure stabilization system in combustion chamber (USC). Its task is to maintain a pressure in the combustion chamber within limits of calculation values. We are concerned here about pressure stabilization first of all during the starting. If, the pressure in the combustion chamber increases above the calculated pressure, then a signal about a pressure rise is forwarded to the amplifying member, which causes the closing of fuel and oxygen flow into the chamber. As result of reduction in driving material the pressure in the combustion chamber drops. In Table 2 are given the most frequently applied USC schemes.

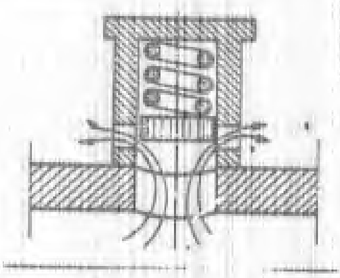
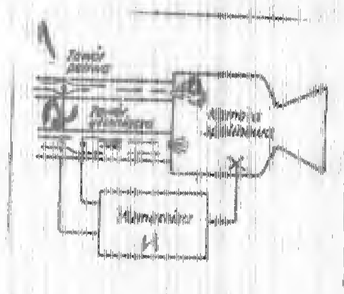
We have so far discussed only the basic systems of an automatic control system applied in engines with turbopump feeding. In addition there are also other systems. For example, in case of applying a rocket engine to an airplane, where most likely will be still another propulsion system, is necessary a special system of coordinating work of both engines. If, in this case, the rocket engine plays a driving role for momentary increase in general trhust, then this system connects the rocket engine only then, if the basic engine functions on maximum thrust. Also a special system will be in case of applying a rocket engine to an aircraft for the purpose of reducing starting time. The purpose of such a system will be not only synchronization with basic engine, but sometimes also disconnection of rocket engine after it finished work.

Regulating system of engine with pressure type feeding.

The automatic control system of an engine with pressure feeding includes the following systems: 1) engine starting system (URS); 2) engine ignition system (UZS); 3) pressure stabilizing system (USC); 4) pneumatic automation system (UAP).

We see here the same systems as in a turbopump feeding system, in addition to the turbopump stabilization system.

Table 2.

USC TYPE	DIAGRAM	BRIEF EXPLANATION
Valve stabilization of pressure		In case of a pressure rise to beyond the calculation value the valve opens and a part of the gas gets out beyond the chamber. Because of great intensities flow through of gas is rarely applied.
Automatic pressure control	 1-fuel valve; 2-oxygen valve; 3-combustion chamber; 4-intersifier.	The signal about pressure rise in the combustion chamber is transmitted to the intensifier and then to the valves. the valves are shut off, and the amount of fuel and oxygen reduced, as result of which the pressure in the chamber decreases.

In addition, we have here a pneumatic automation system. The ignition and pressure stabilizing systems do not basically differ from the very same systems applied in engines with turbopump feeding. But the starting system is basically more developed if we deal in valve and faucet systems.

The operation of the feeding system during the starting can be divided into three basic periods. In the first period the starting system opens electromagnetic valves ($(ZE)_p$, $(ZE)_u$ and ZE), and the gas then comes out from the pressure container (ZC) it goes to the fuel and oxygen tanks and eventually also to the starting fuel tank (PR).

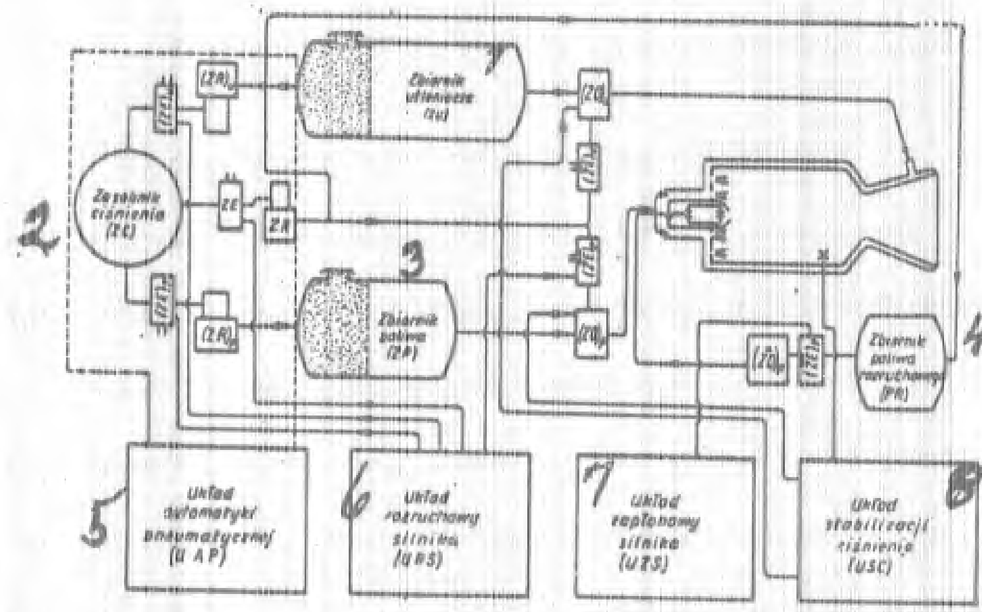


Fig. 3.
Diagram of a rocket engine with designation of automatic control system.

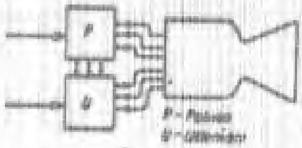
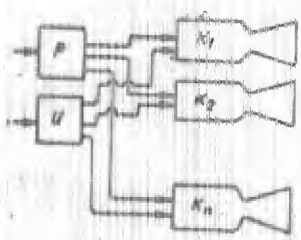
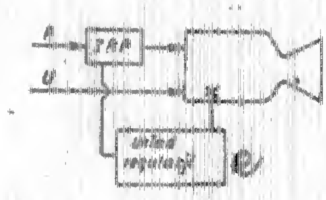
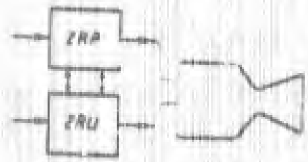
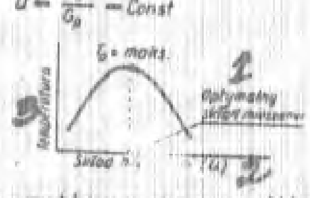
KEY: 1-oxygen tank (ZU); 2-tank container of pressure (ZC); 3-fuel tank (ZP); 4-startinc fuel tank (PR); 5-pneumatic automation system (UAP); 6-engine starting system (URS); 7-engine ignition system (UZS); 8-pressure stabilizing system (USC).

On the way , the pressure of the gas forced out is being reduced in reduction vlaves ($(ZR)_p$, $(ZR)_u$ and (ZR)). In the second period, also with the aid of URS, are opened electromagnetic valves $(\overline{ZE})_p$ and $(\overline{ZE})_u$). The gas then goes to cut of valves $(\overline{ZO})_p$ and $(ZO)_u$) causing the opening of same. The starting fuel and the oxygen arrives at the combustion chamber and ignition takes place. In the third period of starting, valve $(\overline{ZE})_p$ is opened up and then $(ZO)_p$, and the combustion fuel arrives at the combustion chamber. Then comes already normal operation of the engine. The moment of starting fuel combustion and the feeding of working fuel into the chamber must be exactly synchronized.

Regulation system of engine with variable thrust

Recently engines with thrust regulation during operation, find greater and greater application in rocket technology. Such an engine differs with this from a constant thrust engine, that the thrust can be changed in a certain specific interval, as it takes place in turbojet drives. An engine with thrust regulation possibility has the greatest perspectives in jet and rocket aviation. In first case, it is included in composition of driving system having as a basic engine - a jet engine. But in the second case, the liquid fuel rocket engine with regulated thrust is one and basic drive of an aircraft. However, even to rocket drives, especially in cases, in which the complicated flight program of the rocket requires variable change in rocket speed. In table 3 are given short descriptions of automatic control systems of this type of engines.

Table 3

NAME	SCHEME OF SYSTEM	SHORT DESCRIPTION
jump regulation of single chamber engin thrust	 P-fuel U-oxide	with the aid of a special automatic control system (Fig. 4) change in thrust is by leaps.
leap thrust regulation in multichamber engine		thrust regulation is realized by consecutive connection or disconnection of combustion chamber. The more combustion chambers the engine has the variation of in thrust is smoother (at established general thrust).
fluid regulation of thrust	 *-regulation system	change in thrust is realized through regulation of fuel flow through at constant intensity of oxygen flow through. For this purpose serves a special fuel regulation valve (ZRP). It can also be in reverse, that means at an established flow through the addition of oxygen is regulated.
optimum thrust regulation	 $U = \frac{G_u}{G_p} = Const$  1-optimum composition of mixture; 2-composition of mixture (u); 3-temperature.	thrust regulation is realized by changing fuel and oxidant expenditures with the aid of ZRP and ZRU valves. The regulation is such that the ratio of flow through intensity of the oxidizer to the ratio of fuel flow through is always a constant value. This leads to maximum temperature and thus to maximum efficiency.

The system consists of a feeding regulator (RZ), constant fuel and oxidizer regulator (RSPU), valve oxygen regulator (RZU) and (UZ), valve system. The total system includes also a turbopump system (UTP) and combustion chamber (KS) and catalyst (K).

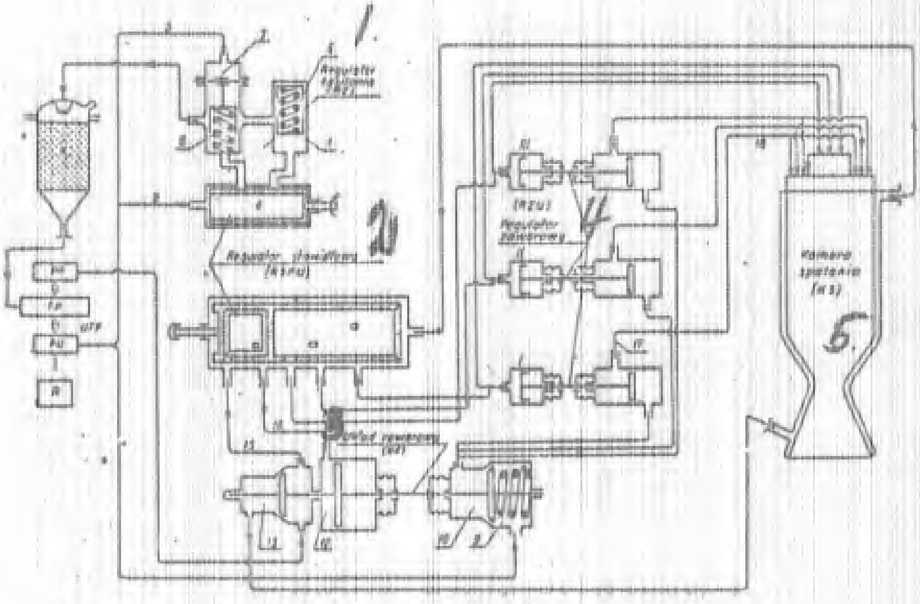


Fig. 4.
One of the possible variants of engine thrust automatic control system.
KEY: 1-feed regulator; 2-valve gear regulator; 3-valve system (UZ); 4-(RZU)-valve regulator; 5-(KS) combustion chamber.

After the turbopump system is started with the aid of a starter (R), the (PU and PP) pumps pump the oxidizer and fuel. First, the oxidizer (in this case hydrogen peroxide) goes to the RZ by two channels (2 and 3). Through channel (2), the oxidizer goes to valve gear (4), and then raising valve (5), it passes around the valve gear (6) and finally flows through to the catalyst (K). The steam created in the catalyst goes to the turbine causing its drive. The number of revolutions in this range is controlled by the tension of the spring (5). Although the turbopump system is already in operation, but the combustion chamber is still inactive. It is a so-called idle run. During this time the oxidizer is supplied also by conduit (8) to doubled valve chamber (9) of the UZ valve system. In this way, the oxidizer valve (10) and fuel valve (13) are closed, and thus the entire movable part (UZ) is shifted to the left. At further rotation of the valve gear (4) (for example by the pilot) turns also the connected to it valve gear (14). The fuel then flows through conduit (15) through valve gear (14) through conduit (16) to cylinder (12) in consequence of which the movable part of this UR is shifted to the right. This brings about the flow through of the oxidizer to the RZU. At this very same time the fuel through valve (13) goes to the valve gear (14). Further rotation of this valve gear causes an overflow of the fuel to valve I (RZU) as well as to the combustion chamber. The flow of the fuel to (I) causes the opening of this valve and the oxidizer goes to conduit (18), and then to combustion chamber. In this way, starts the work of the engine at small thrust value. Turning further the valve gear (14) we consequently change into medium thrust, and later into high thrust. In this case, the action of valves II and III is identical with valve I.

Synchronization systems.

These systems can be divided into two basic groups. The first group includes work synchronization systems of several engines, where each engine has a different feeding system. Such an automatic control system is called outer synchronization system (ZSS-Fig. 5). But to the other group belong systems which have the task of coordinating the work of several engine chambers. In this case, we deal with one feeding system serving several combustion chambers. Such an automatic control system is called internal synchronization system (WSS). In addition to a series of engine, with feeding systems as in case of a single engine, we have there a central engine control system (CUSS). With the aid of this system is possible to connect and disconnect individual engines and coordinate their work at the time of starting. The CUSS is connected with electromagnetic valves of the feeding system. In case, when simultaneous connection of all engines is necessary, the CUSS opens then all valves ($(ZE)_p$ $(ZE)_u$ and (ZE)). In the following sequence also with the aid of CUSS, are opened all electromagnetic valves $(ZE)_p$ and $(ZE)_u$. After these last ones are opened, air passes into the cut of valves (ZO) causing opening of same. The fuel and oxidizer are then transferred into the combustion chamber.

If, we assume, that all engine function on self ignition driving material, then after the fuel and oxidizer reach the combustion chamber, starts ignition, with the aid of CUSS can be steered quite precarious, which means, that it is also possible to connect only one engine or consecutively several.

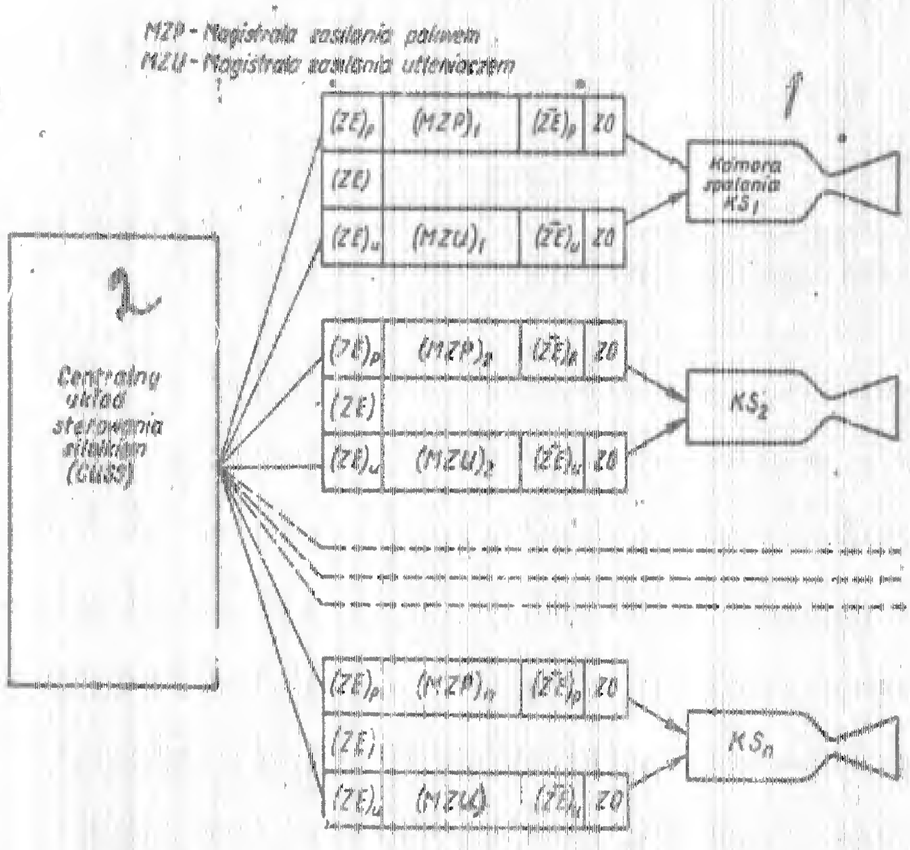


Fig. 5.
General diagram of an outer synchronization system with pressure feeding MZP-main conduit of feeding fuel; MZU-main conduit of feeding oxidizer. KEY: 1-combustion chamber BS_1; 2-central engine control system (CUSS).

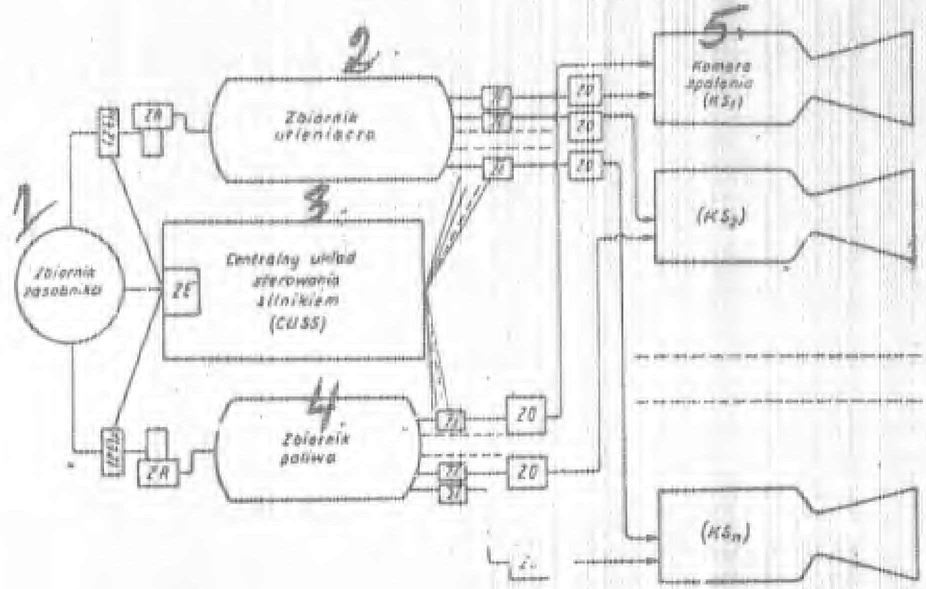


Fig. 6.

KEY: 1-container; 2-oxidizer tank; 3-central engine steering system (CUSS); 4-fuel tank; 5-combustion chamber KS_1.

If, the used fuel is not a self igniting fuel then each engine has of the previously discussed starting system, then each starting system is connected to the CUSS. Connection of URS comes then before the electromagnetic valves (ZE) are connected. If, the work program of the driving system foresees successive engine operation, then in the synchronizing system is also foreseen reverse coupling (SZ). It has the purpose of "nitifying" the CUSS that the given engine stopped working. After receiving such a signal CUSS connects the next engine. In reverse coupling lines, as a warning element is mostly a pressure feeler in combustion chamber or in fuel supplying of conduits, or the oxidizer supplying conduits into the chamber. If the pressure drops, the signal confirming work completion of one engine, is transmitted to CUSS, which in turn connects the next engine. In the internal synchronization system (WSS) one feeding system, together with one fuel tank and one oxidizer tank, serves several combustion chambers. If, it is assumed, that this is a pressure feeding system, then the steering based on consecutive connection and disconnection of engines is with the aid of valves $\overline{(ZE)}$ controlling out of vlaves (ZO). After connection of electromagnetic valves loading the tanks $((ZE)_p$ and $(ZE)_u)$ and the ZE valve, the control system of engine control is prepared for simultaneous or subsequent connection of chambers. The working procedure of such a system (WSS) is already further on similar to the work of ZSS.

In the last chapter was discussed only certain solutions of synchronizing systems. It is clear, that there can be at least several such solutions. They will differ, if they have to be applied to engines with turbopump feeding. The the CUSS will be connected exactly with turbine and pump operation. The working principle of the central steering system of the engine can be different. We often apply an electronic or hydraulic system, but rarely a pneumatic. At times is applied a mixed, e.g. CUSS type hydraulic-electronic system.

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