# OUTLINE OF THE METHOD FOR PREDICTION OF LIFETIME ACHIEVED BY AVIONIC HYDRAULIC DRIVES OPERATED UNDER REAL FIELD CONDITIONS

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***Abstract***

*The presented approach to predict lifetime of avionic hydraulic drives belongs to à priori (accelerated) methods as by its nature it does not require to continue tests until a hydraulic subassembly or drive reaches its boundary value of a structural parameter. The method uses distributions of a random variable with time-dependent variance as models for lifetime prediction. Variations of structural parameters over a discretional period of time are described with use of the Gaussian distribution with the assumption that the course of the process when the structural parameters are subject to deterioration comprises the entire probabilistic characteristic that defines resistance of the hydraulic drive to a wear and tear process. In that context distributions of characteristics for variations of structural parameters were determined for a selected period of time and it served as a basis to find out parameters for the distribution of the defect-free operation time. The completed functional and design decomposition of an example avionic hydraulic drive made it possible to obtain a hierarchical description of the hydraulic drive, to identify its structural parameters that are available during the drive operation as well as to define a set of measurable output parameters of a system, a module (a hydraulic system) and a block (a hydraulic subassembly). The set of measurable output parameters attributable to the hydraulic system in question is described with use of mathematic equations that result from fundamental equations for hydraulic systems dynamics, i.e. the mass conservation law, the principle of momentum and angular momentum conservation as well as the energy conservation law.*

***Keywords:*** *lifetime, probability density function, hydraulic drive, pump delivery, structural parameter, deterioration rate, wear and tear*

## 1. Introduction

The lifetime is such a property of a hydraulic avionic drive that is meant to define its ability to preserve its operable status under specific operation conditions until its operation is terminated. Operation of a hydraulic drive is interrupted by random disturbances that affect the regular operation, consequently the appliance fails to demonstrate the expected lifetime (premature loss of the equipment ability to be operated in accordance with the intended use). Discrepancies between the expected and the actual lifetime can be determined by keeping records on measurable structural parameters of hydraulic drives under real field conditions of their operation. It is undoubtedly associated with the need to use information on amendments of dynamic behaviour attributable to a hydraulic drive that take place under real field conditions, this information proves to be useful both on the design state and during further operation of the appliance.

A hydraulic avionic drive is a specific appliance that has some distinguishing properties that justify the purpose of its specific definition. It has a defined configuration that is represented by mutually collaborating subassemblies and parts that make up its structure aimed at execution of intended functions by the entire drive. It is why the lifetime of a hydraulic drive must be considered as a boundary operation time for subassemblies that make up the drive structure. This boundary time period is limited by the fact that those components are no longer capable to be resistant to the impacts of working factors (input functions). The structure of a hydraulic avionic drive is defined by a number of quantitative parameters that are referred to as structural parameters. Amendments to these structural parameters pose a random process that is affected by various operation factors [1, 2, 5, 6].

## 2. Identification of those structural parameters of hydraulic avionic drives those are available during the operation process

Hydraulic avionic drives are sophisticated structures in terms of their technical design. The interrelationships between individual components of the structure are strictly defined. Owing to these relationships and interconnections the structure is capable to operate and all the components make up a precisely defined unity. Every hydraulic avionic drive should be considered as a complex system, i.e. a system where individual subassemblies can be discriminated and, in turn, each subassembly can be regarded again as a complex system. This assumption enables hierarchical classification (decomposition) of a hydraulic avionic drive as a whole system into functional subsystems. The decomposition process comprises also interconnections and interrelationships between individual subassemblies in order to obtain more primitive and basic relations [9, 13].

The study [7] presents a functional and structural decomposition of a hydraulic avionic drive along with its hierarchical description. For that purpose the following hierarchical structure of a hydraulic avionic drive was adopted: a system, a module, a unit and a node. This classification make it possible to identify parameters that define the drive structure and its operation along with all its subassemblies and to discriminate a set of measurable parameters of a drive (a hydraulic system), a subassembly (a hydraulic module), a block (a hydraulic unit) and a hydraulic node (a hydraulic precision pair). Physical variables that determine circulation of information between modules of a system, between units within a module and between nodes within a unit represent a set of parameters that determine structures and operation of modules, units and nodes.

Extensive examinations of wear processes in rotating hydraulic pumps of the piston (reciprocal) type with a distributing disk and adjustment of the pump delivery as a function of the pump operation time were carried out within the scope of jobs that are reported in [11-13]. Selected examination results are presented in [7, 8]. The analysis of obtained results demonstrates that the set of parameters that are directly correlated with the wear processes affecting pumps during their operation and that unambiguously define their lifetime include: pressure $p_p$ produced by a hydraulic pump, delivery $\theta_p$ of a hydraulic pump, flow rate $\theta_d$ of working fluid drained from a hydraulic pump and flow rate $\theta_c$ of working fluid circulated via the pump cooling contour. The major structural parameter associated with fluid consumption (absorptivity) of the hydraulic system is the flow rate due to internal leaks in the following units: a hydraulic motor, a hydraulic manifold, a hydraulic valve, a hydraulic amplifier and a hydraulic transducer.

The set of measured values for the measurable structural parameter that are recorded during subsequent moment of the operation time $t$ makes it possible to trace gradual alterations of the wear process affecting the hydraulic subassembly.

Alteration of operational recourse available to a hydraulic system can be assessed on the basis of the volumetric coefficient $\chi_{ih}$ defined as the ratio of the hydraulic delivery $\theta_p$ of the supplying system to the fluid consumption (absorptivity) $\theta_{ch}$ of the hydraulic subassemblies (a hydraulic motor with linear motion of its piston $\theta_{chp}$ or a hydraulic motor with rotational motion of its shaft $\theta_{cho}$), i.e.:

$$\chi_{ih} = \frac{\theta_p}{\theta_{ch}}, \tag{1}$$

where $\theta_{ch} = \theta_{chp} + \theta_{cho}$.

Delivery of the supplying system is defined as amount of working fluid supplied to the pressure line during a time unit. Consumption (absorptivity) of a hydraulic system is understood as amount of hydraulic fluid sucked from the supplying system during a time unit.

In practice, the volumetric coefficient $\chi_{ih}$ of a hydraulic system can be evaluated by measuring time and rotation (rpm) of the rotor in the motor that drives the pump for the moment when pressure in the hydraulic system reaches the predetermined value. The time $t_r$ when pressure rises in the hydraulic system during its start-up can be defined by the following equation:

$$t_r = f(\eta_v, \theta_p, p) = f(\chi_{ih}, p), \tag{2}$$

where:
$\eta_v$ - volumetric efficiency of the system,
$\theta_p$ - delivery of the supplying pump,
$p$ - pressure in the hydraulic system.

The time for pressure rise until the predefined threshold in the hydraulic system is calculated from the equation for the flow balance of fluid in the system during its start-up. The balance equation is:

$$\theta_p - a_v p_p - c\frac{dp_p}{dt} = 0, \tag{3}$$

where:
$\theta_p$ - delivery of the hydraulic pump,
$a_v$ - coefficient of flow rate due to internal leaks of the system subassemblies,
$p_p$ - pressure variations in the hydraulic system,
$c$ - hydraulic capacity (capacitance),
$t$ - time when pressure rises in the system.

The relationship (3) makes it possible to calculate the time interval that is necessary to achieve the predefined pressure in the hydraulic system:

$$t_r = \frac{a_v}{c}\ln\frac{\theta_p}{\theta_p - p_p a_v}. \tag{4}$$

For any hydraulic subassembly, the flow rate $a_v$ due to internal leaks is calculated by the formula:

$$\Delta\theta = a_v p, \tag{5}$$

whereas for the entire system there must be taken into account:

$$\Delta\theta_n = \sum_{i=1}^{n}\left(a_{vi} p_i\right). \tag{6}$$

After having substituted the boundary limits for the parameters to the relationship (4) one can obtain the limit value for the pressure rise time until the predefined pressure threshold.

Completed experiments and examination of real avionic systems make it possible to state that a hydraulic avionic drive is able to perform its intended functions when the ratio of the hydraulic delivery $\theta_p$ of the pump to the consumption (absorptivity) $\theta_{ch}$ of the hydraulic system is not less than 0.95, which is noted as $\theta_p/\theta_{ch} \geq 0.95$. Rotation speed (rpm) of the pump driving motor for the moment when the system pressure reaches the predefined threshold is calculated from the following equation for the flow balance:

$$\theta_p = \rho_p n_s - a_{vp} p_p \geq 0.95\ \theta_{ch}, \tag{7}$$

where:
$a_{vp}$ - coefficient of flow intensity due to internal leaks of the pump, calculated from the equation (5),
$\rho_p$ - unit delivery of the pump.

Therefore the limit rpm for the pump driving motor at the moment when the pressure in the hydraulic system reaches the predefined threshold is calculated from the following formula:

$$n_s \le \frac{0{,}95\theta_{ch} + a_{vp} p_p}{\rho_p}. \tag{8}$$

Thus, the variation (timings) for the pressure in the hydraulic system and well as its alterations during movements of hydraulic actuators, such as flaps, undercarriage, aerodynamic brakes, shall be considered as the structural parameter measurable during the entire lifetime of the hydraulic avionic drive. Pressure in the hydraulic system as well as parameters of movements performed by hydraulic actuators can be determined from the equations for:

- movements of the plunger in the hydraulic motor (with linear movements):

$$I_z \frac{dV_s}{dt} = p_s \rho_s - M_u - \rho_s V_s, \tag{9}$$

- flow balance:

$$\theta_p - \rho_s V_s - a_v p_s - c\frac{dp_s}{dt} = 0, \tag{10}$$

where:

$I_z$ - scaled moment of inertia,
$V_s$ - linear speed of the plunger in a hydraulic motor with linear movements of the plunger (or angular speed when a hydraulic motor with rotation shaft is in question),
$p_s$ - pressure drop across the hydraulic pump,
$\rho_s$ - relative consumption (absorptivity) of the hydraulic motor at a specific speed,
$M_u$ - static torque of an external passive load.

For systems with rotational hydraulic motors, pressure values in a hydraulic system, when a rapid switchover of the hydraulic plunger (spool) in the manifold occurs, can be described by means of the following equation:

$$p_{so} = p_u + \omega_{so}\sqrt{\frac{I_z}{c}} = \frac{M_u}{\rho_s \eta_{ms}} + \frac{\theta_p \eta_v}{\rho_s}\sqrt{\frac{I_z}{c}}. \tag{11}$$

For systems with linear hydraulic motors, pressure values in a hydraulic system, when a rapid switchover of the hydraulic plunger (spool) in the manifold occurs, can be described by means of the following equation:

$$p_{so} = p_u + V_s\sqrt{\frac{m_z}{c}} = \frac{P_u}{F_t \eta_{ms}} + \frac{\theta_p \eta_v}{F_t}\sqrt{\frac{m_z}{c}}, \tag{12}$$

where:

$m_Z$ - scaled weight,
$P_u$ - usable force,
$\eta_{ms}$ - mechanical efficiency of the hydraulic motor,
$F_t$ - piston surface.

## 3. Variation of operation resources available to subassemblies of a hydraulic avionic drive during its lifetime

Reduction of operation resources available to subassemblies of a hydraulic avionic drive during its lifetime is caused by wear processes that affect hydraulic nodes (hydraulic precision pairs) of such subassemblies [8] and depends not only on the already expired operation time of these subassemblies but also on their individual properties, e.g. durability and vulnerability to exposures associated with the operating conditions. The gradual decrease of the operational resource is a cumulative effect of various wearing and tearing factors that act over the measured time. In fact, the wear rate of a hydraulic node (a hydraulic precision pair) is a function of many factors that can be generally considered as random variables. Therefore the wear rate of a hydraulic node is a function of random arguments and it is also the nature of the node operation until the threshold limit of wear is reached, i.e. when the structural parameter achieves its boundary limit.

The operation process of hydraulic equipment shows that deterioration of the structural parameter $y$ attributable to a hydraulic drive (increase of the average wear effect) during the time interval $t$ is constant with the initial condition for the starting moment $t = 0$, $y = 0$. The foregoing analyses assume that distribution of the random variable $y$ for the specific population of hydraulic subassemblies referred to the moment of $t$ is the Gaussian distribution (Fig. 1). The symptom that indicates reduction of operation resources available to subassemblies of a hydraulic avionic drive is transition of the measurable parameter $y_i$ of that subassembly, included into the set of parameters $Y = \{y_i\}$, where $i = 1, 2, 3$, from the state of $x(t)$ at the moment of $t$ to the state of $x_1(t)$ at the moment of $t_1 > t$. The supremum for any subassembly of a hydraulic avionic drive is the moment when the measurable parameter $y_i$ included into the set of parameters $Y = \{y_i\}$, where $i = 1, 2, 3$, exceeds the threshold limit determined by the interval of tolerances. The probability $P_u$ that the hydraulic subassembly is no longer suitable for its intended application (lifetime boundary) is the probability that the parameter $y_1$ reaches its boundary limit:

$$P_u = 1 - P\,(y_1 - \Delta y_1 < y_1 < y_1 + \Delta y_1)\,, \tag{13}$$

$$P_u = 1 - \int_{y_i - \Delta y}^{y_i + \Delta y} f(y_1)\,dy_1\,, \tag{14}$$

where $P_u$ stands for the probability that the value of $y_i$ still remains within the interval of tolerances $y_1 - \Delta y_1 < y_1 < y_1 + \Delta y_1$ and $f(y_i)$ is the probability density of the fact that the $y_i$ parameter remains within the tolerance interval.

Let us assume that operating conditions for a hydraulic avionic drive remain unaltered during its entire lifetime as well as: the drive is regarded as an irreparable object, change of its technical condition is associated with gradual alteration of its structural parameter, the fact that the structural parameter belongs to a specific interval of its values is equivalent to its operable status, the structural parameter has its defined upper and lower limits of variations (infimum and supremum), measurements of the structural parameter values attributable to the hydraulic drive are carried out during its operation by means of a discrete system with the step of $h$ within time intervals $\Delta t$, technical condition of the hydraulic drive can be evaluated by variations of flow resulting from variation of plays and damages to surfaces of components that make up the entire hydraulic drive.

Prediction of the lifetime expected for hydraulic avionic drives with consideration to their wear and tear processes leads to seeking for distributions that represent probability densities for the time moments when structural parameters of drives change their values until the boundary limits of them are reached. Alteration of structural parameters attributable to hydraulic avionic drives is a random process $y(t)$ that is affected by a wide spectrum of operation factors. The simplest representation of a random function is a one-dimensional function for distribution density $f(y,t)$ that defines distribution of the random variable $y(t)$ at discretionary moments of time $t$. Under the assumption that the cumulative distribution function of the random process changes in a monotonous manner, i.e. it is an increasing function, the function $f(y,t)$ for the distribution density is defined for any specified moment of time and interrelationships between values of the random function for any two different moments of time $t$ are strictly determined.

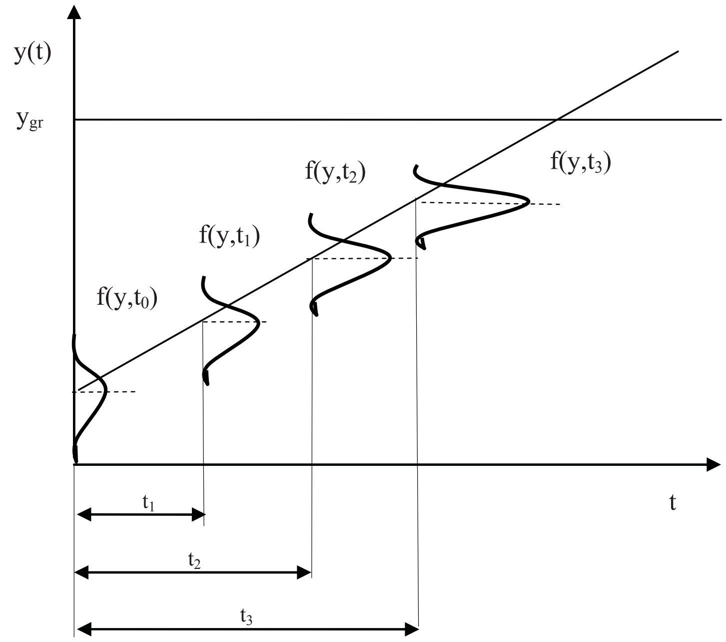


*Fig. 1. Deterioration of the structural parameter y attributable to a hydraulic drive (increase of the effect of average wear) over the time as well as distributions of variations to the structural parameter f(y,t) after the time intervals* $t_1$, $t_2$, $t_3$

The distribution of the random variable *y(t)* for the specific population of hydraulic subassemblies with regard to the moment of *t* is the Gaussian distribution. The function for distribution density adopts the following form:

$$f(y,t) = \frac{1}{\sqrt{2\pi}(\sigma_a + \sigma_b t)} \exp\left[\frac{(y - m_a - m_b t)^2}{2(\sigma_a + \sigma_b t)^2}\right]. \tag{15}$$

In turn, for any specified moment of time $t_n$ the function for distribution density is determined by the expression:

$$f(y,t_n) = \frac{1}{\sqrt{2\pi}(\sigma_a + \sigma_b t_n)} \exp\left[\frac{(y - m_a - m_b t_n)^2}{2(\sigma_a + \sigma_b t_n)^2}\right]. \tag{16}$$

The functions for moments of the structural parameter, i.e. its expected value (EV) $m_y(t)$ and the mean square deviation (MSD) $\sigma_y(t)$ may be approximated by means of the following linear relationships:

$$m_y(t) = m_a + m_b t\ , \tag{17}$$

$$\sigma_y(t) = \sigma_a + \sigma_b t\ . \tag{18}$$

The constant coefficients $m_a$ and $m_b$ for the relationships (17, 18) can be calculated with use of the formulas:

$$m_a = \frac{t_{i+1} m_y(t_i) - t_i m_y(t_{i+1})}{t_{i+1} - t_i}, \tag{19}$$

$$m_b = \frac{m_y(t_{i+1}) - m_y(t_i)}{t_{i+1} - t_i}. \tag{20}$$

The $\sigma_a$ and $\sigma_b$ coefficients are calculated with use of similar formulas.

When the structural parameters for a separate random process change at a constant rate, the linear model for the parameter variation can be applied:

$$y(t) = \alpha t + \beta \,, \tag{21}$$

where $\alpha$ = tg $\varphi$, and $\varphi$ is the inclination angle for the curve that reflects variation of the structural parameter whilst $\beta$ stands for translocation of the structural parameter variation.

The deterioration rate for a structural parameter $y$ attributable to the hydraulic drive (increased wear effect of the hydraulic node) can be described by the following relationship:

$$\upsilon = \frac{dy}{dt} = c + ky \,. \tag{22}$$

After transformation of the equation (22) and integration of both the left and right sides respectively for time and for increase of the wear effect and assuming that after the time interval $t_1$ the average value of the structural parameter alteration is $y_1$, the following result is obtained:

$$t - t_1 = \frac{1}{k} \ln \frac{c + ky}{c + ky_1} \,, \tag{23}$$

$$y = \left( y_1 + \frac{c}{k} \right) e^{(t - t_1)k} - \frac{c}{k} \,. \tag{24}$$

Substitution $\frac{1}{k \ln e} = A$ and $\frac{c}{k} = h$ into the equation (23, 24) and conversion of natural logarithms into common ones leads to the following expression:

$$y = (y_1 + h) 10^{\frac{t - t_1}{A}} - h \,. \tag{25}$$

The parameter $A$ is actually the lifetime factor as it tells how fast the structural parameter of the hydraulic drive is subject to deterioration whilst $h$ is the bias factor (defines translocation of the curve).

The upper limit of the confidence interval for deterioration of the structural parameter attributable to the hydraulic drive is calculated from the equation:

$$y_{\max} = (y_1 + \sigma_1 + h) 10^{\frac{t - t_1}{A}} - h \,, \tag{26}$$

whereas the lower limit for the confidence interval is defined as:

$$y_{\min} = (y_1 - \sigma_1 + h) 10^{\frac{t - t_1}{A}} - h \,, \tag{27}$$

where:

$y_{max}$ - the current upper limit for the confidence interval,

$y_{min}$ - the current lower limit for the confidence interval,

$\sigma_1$ - the mean square deviation for deterioration of the structural parameter over the time interval $t_1$.

Coefficients $A$ and $h$ can be determined from the relationships:

$$A = \frac{t_2 - t_1}{\lg \frac{\sigma_2}{\sigma_1}} \,, \tag{28}$$

$$h = \frac{y_2 - y_1 \dfrac{\sigma_2}{\sigma_1}}{\dfrac{\sigma_2}{\sigma_1} - 1}, \tag{29}$$

where $y_2$ and $\sigma_2$ stand for average values for the structural parameter variation and its mean square deviation at the moment of $t_2$.

## 4. An example for application of the method

The relationships presented in Par. 2 served as a basis for calculation of selected structural parameters associated with the aircraft hydraulic system, i.e. the rise time $t_r$ for pressure in the hydraulic contours during the interval from the start-up until he moment when the pressure reaches the required value, the time $t_k$ necessary for the full-distance movement of a hydraulic actuator (a flap) from one limit position to the reciprocal one, the fall time $t_w$ for pressure in the hydraulic contours within the range of characteristic values after switching the aircraft engine off as well as the maximum pressure $p_t$ in the hydraulic system. The time $t_r$ that is necessary to reach the characteristic value for this aircraft type (16 MPa) should never be longer than 7 s. The fall time for pressure in the hydraulic system within the range of characteristic values (from 18 MPa to 15 MPa) after switching the engine off for this aircraft type should never be shorter than 15 s. The time $t_k$ necessary for the full-distance movement of a flaps from one limit position to the reciprocal one should fall within the interval from 4.5 s to 6.0 s. Pressure in the hydraulic contours when no actuator is in operation should never be lower than 20 MPa.

Figure 2 presents pressure variations in the aircraft hydraulic system when the engine is switched on and the hydraulic system has been operated in the aircraft for 448 hours. Figure 3 presents pressure variations for the same aircraft after 925 hours of the hydraulic system operation and Fig. 4 – after 1443 hours of its operation. For comparison, Fig. 5 comprises diagrams for pressure variations in the aircraft hydraulic system when the driving engine is on and the curves with measurements after 448, 925 and 1443 hours of operation are superposed on a single plot. The three diagrams are biased due to missynchronization of the test time for the aircraft (the tests are carried out by an aircraft technician). Analyses of the pressure timings (Fig. 5) reveal that values for selected structural parameters ($t_r$, $t_k$, $t_w$, $p_t$) of the hydraulic system are subject to alterations in pace with the operation time of the hydraulic system in the aircraft. Increase of the rise time $t_r$ for pressure in the hydraulic system as well as the time $t_k$ necessary for the full-distance movement of a hydraulic actuator from one limit position to the reciprocal one give the evidence about drop of the hydraulic pump delivery and increase of the fluid consumption (absorptivity) by the hydraulic system subassemblies. Decrease of the maximum pressure $p_t$ in the hydraulic system in pace with its on-board operation time confirms that the hydraulic pump delivery decreases in time with simultaneous increase of fluid consumption (absorptivity) by the hydraulic system subassemblies. Timings for pressure variations in the aircraft hydraulic system and plots for variations of structural parameters as a function of operation time expired for the hydraulic system (see Fig. 2, 3, and 4) along with relationships from Par. 2 and 3 made it possible to calculate average rate for deterioration of structural parameters, i.e. $t_r$, $t_k$, $t_w$, $p_t$. Thus, the average deterioration rate for the rise time $t_r$ of pressure in the aircraft hydraulic system is 0.46 s per each 100 working hours of the system on the aircraft board. The average deterioration rate for the fall time $t_w$ of pressure in the hydraulic contours within the range of characteristic values after switching the aircraft engine off is 0.47 MPa per each 100 working hours of the system on the aircraft board. The average deterioration rate for the maximum pressure $p_t$ in the hydraulic system when no actuator is in operation is 0.1 MPa per each 100 working hours of the system on the aircraft board.

Therefore the estimated lifetime of the hydraulic system due to the rise time $t_r$ of pressure in the hydraulic system is $T_r$ = 2100 hours, due to the fall time $t_w$ of pressure in the hydraulic system is $T_w$ = 1900 hours and due to the maximum pressure $p_t$ is $T_p$ = 2500 hours.

The resulting lifetime of the aircraft hydraulic system shall be determined by the condition:

$$T = \min(T_r,\ T_w,\ T_p) = \min(2100,\ 1900,\ 2500) = 1900 \text{ hours} . \tag{30}$$

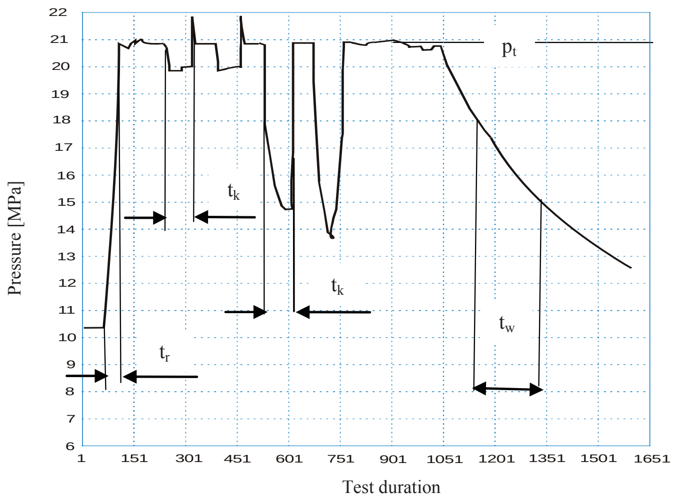


*Fig. 2. Plots for pressure variations in the aircraft hydraulic system after 488 hours of operation when the driving motor is on*

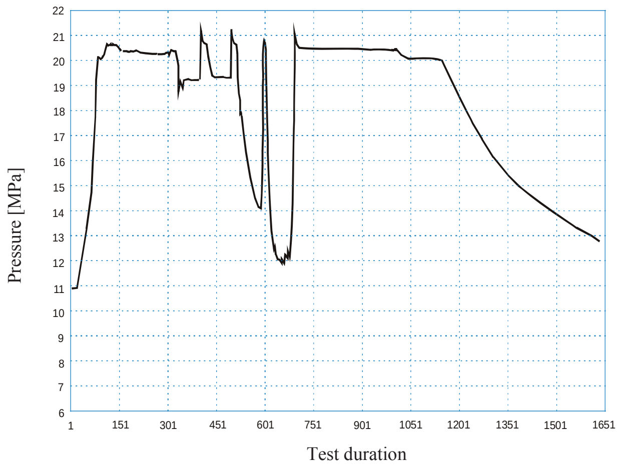


*Fig. 3. Plots for pressure variations in the aircraft hydraulic system after 925 hours of operation when the driving motor is on*

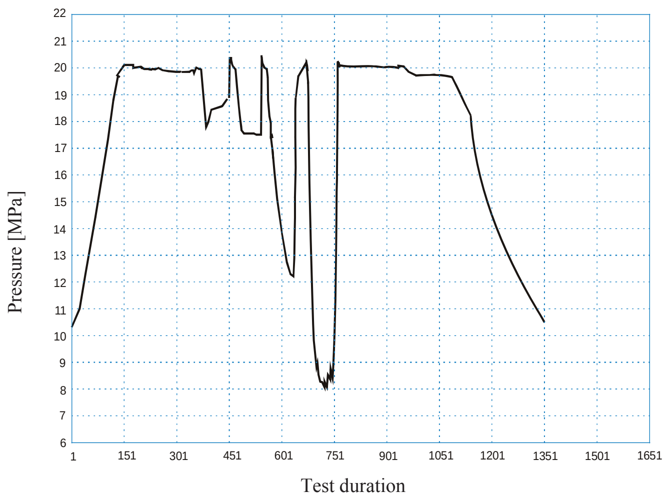


*Fig. 4. Plots for pressure variations in the aircraft hydraulic system after 1443 hours of operation when the driving motor is on*

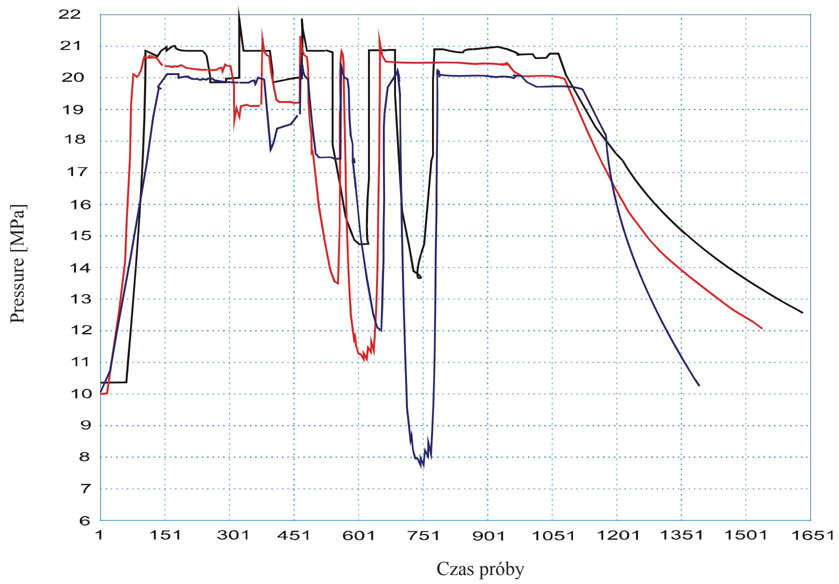


*Fig. 5. Comparison of plots for pressure variations in the aircraft hydraulic system after 488, 925 and 1443 hours of operation when the driving motor is on*

## 5. Summary and conclusions

The existing practice for evaluation and prediction of lifetime for avionic hydraulic drives and their subassemblies is based on the *à posteriori* method when the analysis of time intervals associated with fault-free operation of the drive is carried out, where fault-free operation is assessed by alterations of technical parameters of the drive until that drive parameters reach the values that are considered, by virtue of various criteria, as the status of inoperability. This approach needs to perform long-term examinations of all the subassemblies that make up the hydraulic drive until they prove to be inoperable. Such examinations that enable à posteriori determination of functional and numerical characteristics of the wear process are expensive and take a lot of time. What is worse, the obtained results can be adapted to drives and subassemblies of similar classes only with some approximation.

This paper presents another approach to estimation of lifetime exhibited by avionic hydraulic drives and their subassemblies. The suggested method is based on the analysis of the process determined by deterioration of structural parameters associated with hydraulic drives and their subassemblies and needs to find out distributions for characteristics of variables that represent structural parameters of hydraulic drives for the defined test durations. Next, the parameters for distribution of the fault-free operation time intervals can be determined. The method assumes adoption of the model for the lifetime function with distribution of the random variable where the variance is time-dependant. Application of the method is limited to such cases when variation of structural parameters of the hydraulic drive at any moment of time $t$ can be described with use of Gaussian distributions and diversity of operation conditions affect in similar manner to the intensities of the deterioration process associated with expiring of operation time (the wear processes run independently). To establish the feasibility for individual prediction of structural parameters it is necessary to find out how fast these parameters are changed and how intense the course of the random process in altered. Quantification of the alteration degree of stochastic processes can be performed with use of the confounding factor described in the study [3]. If alterations of the random process are not very strong, it is possible to use formulas (26) and (27) to define boundaries of confidence intervals individually for each course of the stochastic variation. If no alteration to a process course exists then any separate course of the process would be described with used of the equation (25) with substitution of deterioration for a structural parameter attributable to the entire population with the deterioration of a parameter for a specific unit.

In order to use the probability density function of structural parameter variations for calculation of the lifetime it is necessary to define moment coefficients of that function with use of both the credibility function and data from actual variation of a structural parameter over the operation period. It is assumed here that the course of the structural parameter deterioration incorporates the full probabilistic characteristic of the hydraulic drive subassemblies in terms of their resistance to the wear and tear processes. The credibility function is a function of unknown parameters whilst the experiment result is defined and represents the product of probability density functions for the functional parameter. When to assume that the values of the functional parameter as a time-dependant function are given for granted, the credibility function is then considered as the function of unknown parameters associated with the probability density function. Estimators for the highest credibility can be found in the way as described in [4].

The presented method for lifetime prediction of avionic hydraulic drives and their subassemblies drives belongs to à priori (accelerated) methods as by its nature it does not require to continue tests until a hydraulic subassembly or drive reaches the boundary value of a structural parameter. In practice, prediction of the lifetime can be carried out by analysis of numerical values adopted by structural parameters that correspond to the wear and tear degree of hydraulic system components. Wear degree of the hydraulic drive is measured by deterioration of a structural parameter associated with delivery, ability to maintain the fixed position, volumetric efficiency, etc.

Practical investigations of plunger (piston) hydraulic pumps confirm that the proposed method enables estimation of their lifetime if variation of the associated structural parameter as a function of operation time is known. However, it must be noted here that the presented method does not take account for all aspects associated with random nature of the wear and tear process, typical for subassemblies of hydraulic drives and fails to give an unambiguous answer on the confidence interval of the result and expected range for its variation.

Due to the fact that hydraulic avionic drives are pretty sophisticated devices, they can be decomposed to relatively simple and separate functional and design subsystems. The completed functional and design decomposition of an example avionic hydraulic drive makes it possible to obtain a hierarchical description of that hydraulic drive suitable for identification of its structural parameters that are available during the drive operation as well as to define a set of measurable output parameters of systems, modules and blocks. The set of measurable output parameters attributable to the hydraulic system in question should be described with the use of mathematic equations that result from fundamental equations for hydraulic systems, i.e. the mass conservation law, the principle of momentum and angular momentum conservation as well as the energy conservation law. Moreover, for complete description of measurable output parameters it is necessary to define boundary values and initial conditions for all the hierarchical levels, i.e. for systems, modules and blocks.

The presented approach to estimation of lifetime is used to switchover from operation of hydraulic avionic system on the basis of their technical resources (safe lifetime) to operation on the basis of actual technical condition (permissible level of wear). This switchover strategy for hydraulic avionic drives needs prediction of their lifetime as well as the lifetimes of their subassemblies on the basis of structural parameters that are available (measurable) during operation of the combat aircrafts.

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