Szent István University

DEVELOPING MAINTENANCE SYSTEM OF SMALL AIRCRAFT: WEAK POINT RECONSTRUCTION

Thesis of the doctoral (Ph.D) dissertation

Rajmund Lefánti

Gödöllő
2011

The doctor's school

designation: **Mechanical Engineering Ph.D School**

discipline: **Agricultural Technical Science**

head of school: **Dr. István Farkas**
professor, DSc
Szent István University,
Faculty of Mechanical Engineering
Gödöllő

Supervisor: **Dr. habil. Gábor Kalácska**
professor, CSc
Szent István University,
Faculty of Mechanical Engineering
Institute for Mechanical Engineering Technology
Gödöllő

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Approved by head of school Approved by supervisors

CONTENT

1. INTRODUCTION, GOALS

1.1. Actuality of theme

The quick development of manufacturing technologies of machine elements and of the producing methods of construction materials influenced also the maintenance methods and materials so the different maintenance strategies developed. The changes concerning the provision, the view in the maintenance strategies constitute really a part of continually more perfect analogy of the customer expectations. Accordingly the activities belonging to the maintenance category also increased. One is sure as an integral part of the machine complete course of life the engine plant maintenance now comes to the front as an integral part of product management or it is dealt with separation and as „outsourced” but there isn’t a negligible standpoint at planning and application of machines.

I thought useful to work out an arranging principle during my research work because of the complexity of maintenance strategies. This helps to compare certain strategies.

The maintenance strategies have developed to the point that implementing certain axioms already take on industrial specific complexion, appear professional domain systems in organizing engine plant maintenance, in instruments, in technologies applied, in carrying out processes and mechanism making decision.

1.2. Research tasks set

I have established shortcomings concerning the maintenance of small aircraft during studying technical literature. Deriving from shortcomings it proved useful to work out a model containing itself the maintaining/servicing activities of the present airworthiness but beyond that contributes to the appropriate putting down, check up of different activities. I thought it reasonable within the model to be worked out a „Complementary technical information” module to be joined closely to the maintenance tasks to be integral part of elastic compliance to the information social relations.

The work out a new maintenance model is a complex engineering task which after clearing the technical literature conceptions and making accurate of its content elements has to aspire betide working out the content elements of the model to present its reconstructions task for filling up the information module for this purpose.

The main steps of the research tasks:

- Short survey and defining of conceptions used in service field. Comparing the maintenance strategies and evaluation with the application of series of questions the „what, when, how, is measured, and after who, what makes".
- Analysing the maintenance practice of small aircraft concerning strategies.
- Developing the maintenance model of small aircraft concerning the insertion possibility of „weak point" reconstructions into the subsystem.
- Weak point reconstruction and its results, working out a specimen model: to determine, to evaluate the technical information's concerning the landing shaft from which to establish conclusions, suggestions, aggravations regarding to the maintenance system of small aircraft.

2. MATERIAL AND METHOD

2.1. Developing the maintenance system of small aircrafts

I have worked out a new module-system maintenance model presentable in bloc-pattern based on service strategies cleared in technical literature survey. The exact describe of the information channels worked out during system organization, the certain levels, developing hierarchies, describing the clarification of availabilities and legalities constitutes the basis of further informatic program development.

I have worked out and filled up a weak point reconstruction for presenting the system for practical use of the model technical information module.

2.1.1. Plastic machine-element applied in small aircraft, as weak point

In case of small aircrafts the 20 - 30 year old construction is obsolete mainly considering the material selection.

As a practical problem the silent-bloc (elastic longitudinal-seating support) at the attachment of landing shaft in a Cessna 172-type aircraft manufactured in the years of 1970 broke down repeatedly, many times.

The outer support has to be checked at Cessna 150-type after each 1000 hour or every 3 year, at 172-types after each 1000 hour but only at plate spring constructions concerning the landing shaft. The manufacturer doesn't take measures in no kind of instructions concerning the service of elastic support (seating) in case of pipe cross-section landing shaft.

The deterioration of PUR-seating at Cessna 172-type means the blot (weak point) to be repaired by reconstruction. Signs referring to breakdown could be observed in the setting - in place, too (Figure 2.1.). The plastic between the outer steel-bush of silent-bloc and the landing shaft almost crumbled away because of repeated load. Figure 2.2. shows the damaged part in disassembled position. It can be seen in the Figure 2. that the original PUR-seating totally deteriorated. The inner part of the PUR bush extenuated, cracked and the material protruded towards the outer flange of the silent-bloc, surely here it could freely deformed.

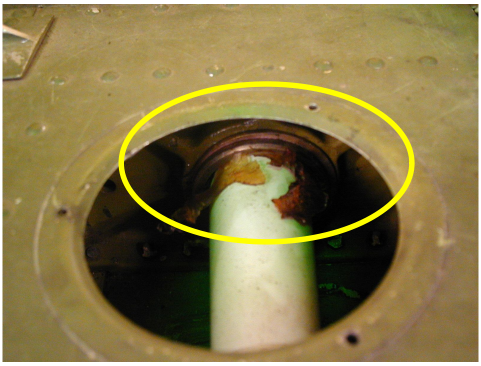


Figure 2.1. The damaged machine element installed position

Figure 2.2. The damaged machine element in disassembled position

2.1.2. Aim of reconstruction of machine-element broken down

The landing shaft seating susceptible to breakdown means risk from aviation safety standpoint. The question can be raised with good reason whether the blot (weak point) can be replaced with solution containing new, up-to-date materials, where the operation load doesn't result returning breakdown.

My further reconstruction activity:

- To propose replacing the original PUR material with elastic seating by other plastic or by plastic mating.
- My further aim is to determine that characteristic load and limit based on which it is necessary checking the machine-element given, independently that just in which period is the aircraft service. It reaching the value determined it is proposed to supervise the machine-element, maybe its replacement. By this characteristic parameter the incomplete service instruction can be completed.

2.1.3. Choosing the original machine-element and material(s) tested

The material of the elastic longitudinal bed resulted manifold break downs corresponds to the PUM 70A cast polyurethane basic material obtainable in today's commerce.

Considering that the characteristic break down of the PUM 70A basic material is the fatigue and abrasion, I have chosen as a substituting material the PUM 60A and PUA 90A basic materials having similar elastic but better fatigue characteristic. As an alternative solution the Docapet TF composite material can be advantageous at forming multi-layer structure as sliding surface.

2.2. Steps of testing the machine-element broken down

The fallowing prints include the process of complex testing of the machine-element broken down, and the evaluation, furthermore it can be seen in Figure 2.3.

- Determining the material, the quality, the composition of the machine-element broken down.
- Determining the properties of the original material and the materials serving as believed substitute materials.
- Determining the load effecting landing shaft by theoretical way.
- To make an appliance suitable to measure the load effecting the aircraft.
- Measuring the load effecting the aircraft in real condition.
- Setting up the mechanical simulation model and giving the test parameters from the properties determined in the previous points. Based on the model the stresses and displacements can be determined in the silent-bloc.
- Developing an equipment suitable for laboratory fatigue-abrasion tests.
- Carrying out rapid laboratory fatigue-abrasion tests in overloaded condition.
- FEM (Finite Element Method) analysis to reveal the connection between the real stresses and the limiting load number.
- Evaluating the results, encase in the technical information module of the maintenance system developed, in the maintenance instruction.
- Reach a conclusion. Material, material-pair suggestion, setting the value of load limit or load range.

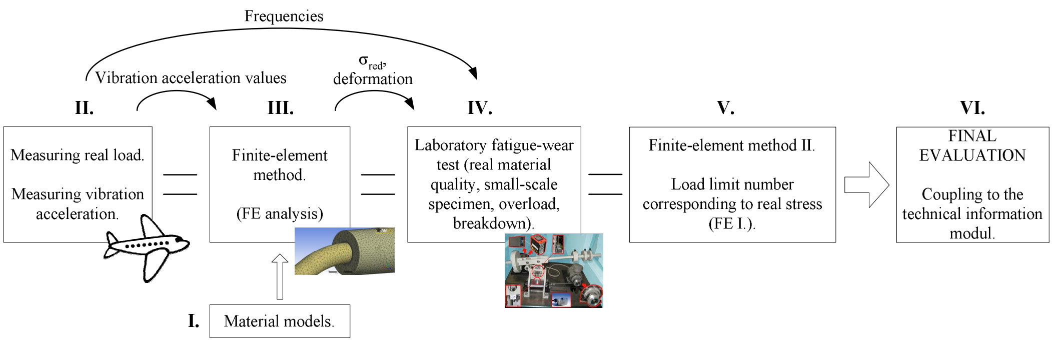


Figure 2.3. Complex testing, evaluating system

3. RESULTS

3.1. Demonstrating the new system model

The program to be made based on the model serves the further development of operation and service concerning the small aircraft so by helping with its application several users. The survey of information picks up speed by its use, which for example results time-saving during service operations. The actives given are documented so they can simply be checked up. The program to be made based on the model provides possibility for professional consultations (with message sending wall character) between operating/maintenance organizations. In case of returning defect phenomenon a method arises: to correct the defend, suggestions can be drawn up, reconstruction planning can be suggested, made (with proper permit), technical conversations can be continued (all these in the „Supplemental technical information" module). I show the main content elements of the new model planned by me in Figure 3.1.

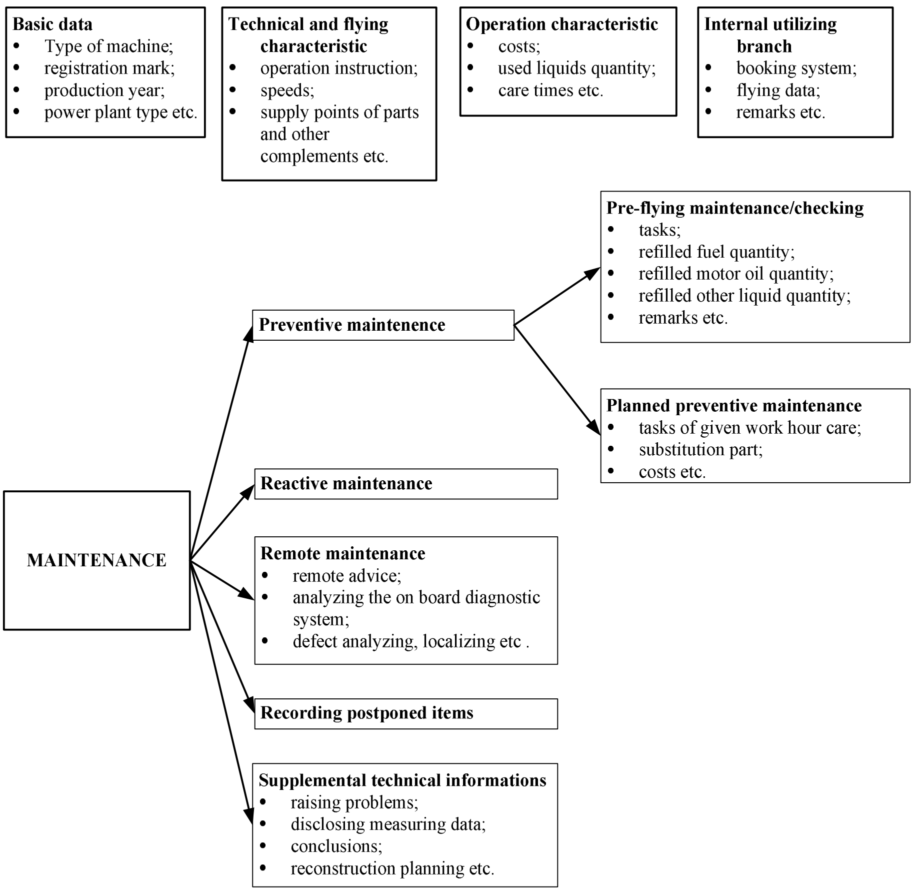


Figure 3.1. Containing structure, main modules of small aircraft, new maintenance system

3.2. Determining material properties

I have worked out filling up the technical information module the reconstruction of the break down of landing shaft bed made from PUR-material for the Cessna 172-type small aircraft mentioned in 2.1.1. section.

I carried out tensile - and compression tests with the materials examined.

I determined the average tensile strength (R_m) and the Young's modulus of the elasticity (E) which can be seen in Table 3.1.

Table 3.1. Values of tensile strength (R_m) and Young's modulus of elasticity

	Docapet TF	PUM 60A	PUM 70A	PUA 90A
R_m [N/mm^2]	64,875	32,428	39,151	35,967
E [N/mm^2]	2134,266	2,075	3,042	4,713

I have elaborated with „section-matching" method the diagrams of the compression tests matching suitable the values measured to use as a material model in the FEM-system (Figure 3.2.).

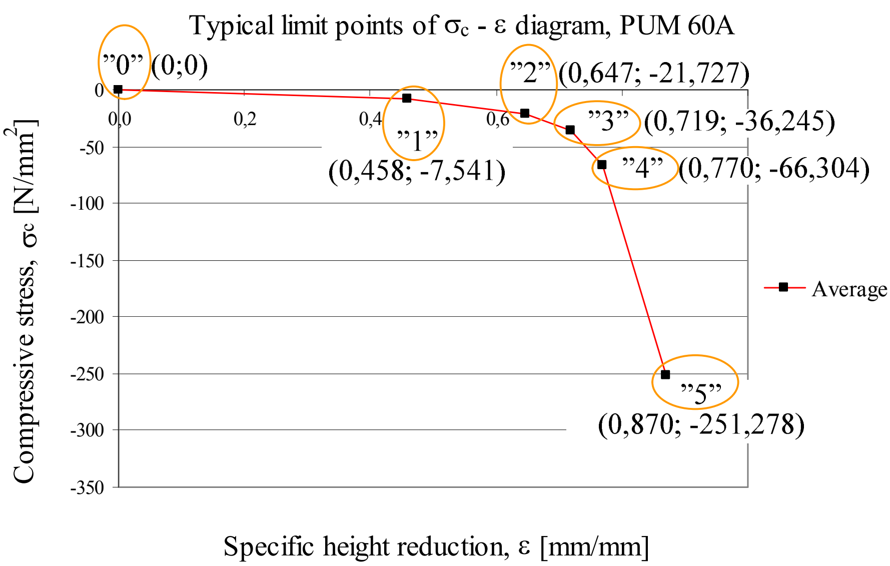


Figure 3.2. Typical limit points of σ_c - ε diagram, PUM 60A

I defined the limit points by which help it can be explained the sections of non-linear material model used for numerical modelling (Figure 3.2.).

3.3. Measuring the aircraft loads in real conditions

It is very complex task to measure the loads befalling to the aircraft to the landing shaft and from this to the silent-bloc.

I have developed and made a measuring-system capable to measure acceleration/vibration-acceleration determining the load befalling to the certain machine-element (Figure 3.3.).

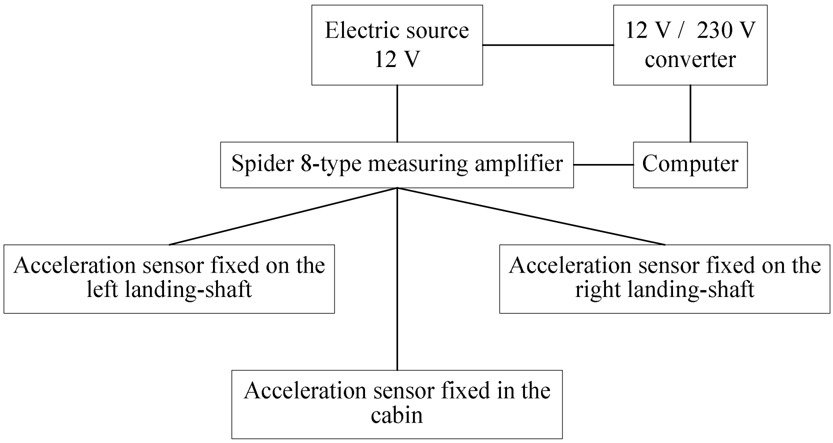


Figure 3.3. Sketch of the measuring-system suitable measuring accelerations arising in the light-aircraft

On the spot of measurings the airport has got concrete cover and grassy fields can be found. Five-five landings and take-offs were made on the concrete cover and grassy fields.

3.3.1. Evaluating the acceleration results

From the acceleration results measured in the framework and in the landing shafts the results measured in the framework were used in further examinations and use for mechanical modelling.

Among the measuring directions at the vertical „z" direction it could be unambiguously separated the various characteristic aeronautic conditions. That six sections can be seen in Figure 3.4. which can be separated during measuring and flight.

The names of certain sections:

I. Landing process, in the air;
II. Moment of landing;
III. Section of decelerating taxiing on the field;
IV. Section of accelerating taxiing on the field;
V. Section after the moment of take-off;
VI. Take-off process in the air.

The examination of sections after these happened separately. I used Fourier transformation (FFT) examining the sections. As results of FFT I got vibration acceleration-frequency values from the vibration acceleration-time functions.

This guaranteed for us that I could determined the repetition number (frequency) of load belonging to the characteristic acceleration values. An example pricked out of Fourier transformation can be seen in Figure 3.5. The characteristic acceleration values are marked in the Figure so, as an exposed value (A), as well as a characteristic section (B)).

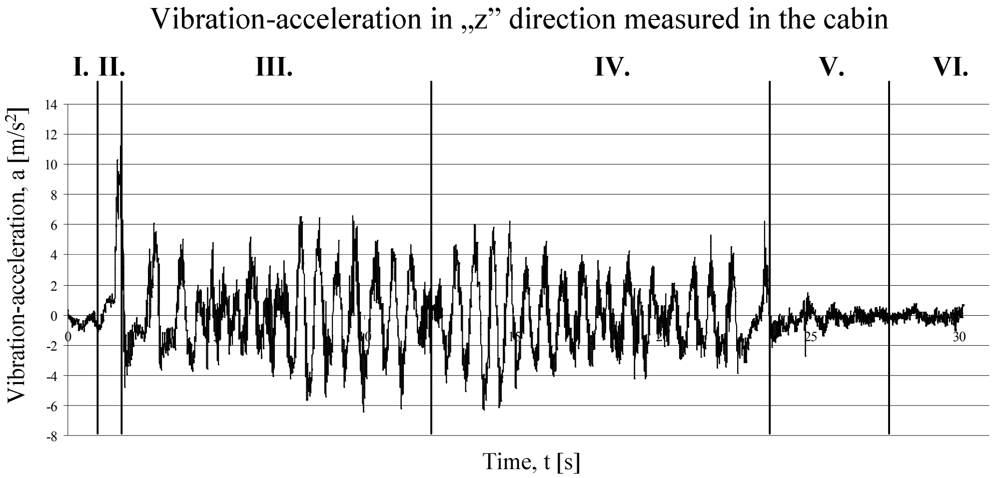


Figure 3.4. Characteristic sections of vibration-acceleration in „z" direction in the function of time measured in the cabin

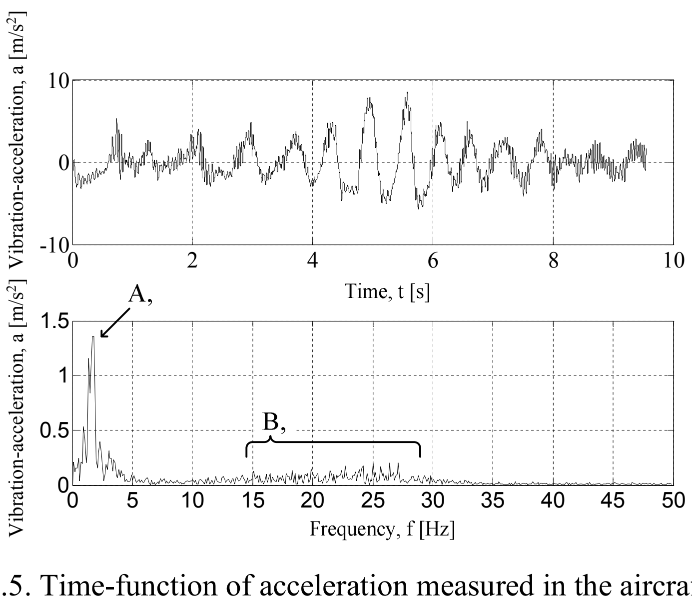


Figure 3.5. Time-function of acceleration measured in the aircraft and FFT frequency spectrum, in the section of decelerating taxiing on the field, „z" direction

It can be stated by knowing the results that the breakdown of the silent-bloc then happens sooner if the load is accompanied with much higher repetition number.

Knowing this it can be established that fact the critical sections considering the silent-bloc are the decelerating/accelerating taxiing on the ground (III., IV. section) and not the moments of landing as well as take-off.

3.4. Landing shaft mechanical examination with simulation

The measurings with real time carried out on the aircraft and their results as well as the results of material testing give due base to carry out mechanical simulation examinations (Finite-element method, FEM) on the landing shaft silent-bloc unit. I have used the Ansys Workbench 11 program for the FEM simulation.

During the program I have completed the real model of the landing shaft and silent-bloc. Among the parameters to be set for the run of the simulation the various material properties and the acceleration values in different directions measured occurred.

By executing the simulation I determined the reduced stress arisen in the plastic bush of the silent-bloc as well as the magnitude of deformations.

The characteristics determined appeared as input parameters at the laboratory rapid fatigue test.

3.5. Laboratory fatigue-abrasion test

I have made an equipment for laboratory fatigue test capable to clamp a small-scale specimen to model the ruin of the silent-bloc.

The DIN 50322 standard gave the basis of the test, within I took the 6. testing category into consideration, namely the model test with specimens having simple shape.

The theory of fatigue test was given by the "Locati" rapid fatigue test applied for steels. During the test the material to be fatigued is exposed to 10^5 repeated load at each increasing load level. During these loads the material tested is ruined.

The fatigue test applied by us differs from the previously mentioned that we adapted the test theory to high elasticity elastomer.

The fatigue of the specimen to be tested is carried out with a carriage making straight line reciprocating motion, on the other hand the specimen is pressed by a load vertically to steel base plate (Figure 3.6.). This is a complex mechanical and tribological fatigue where the contact surfaces also deform and also rub (stick) as in the real landing shaft seating.

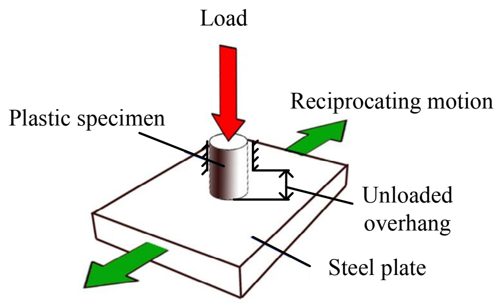


Figure 3.6. The specimen loads

I determined the specimen determination by visual examination in every cases. I considered the specimen deteriorated if it could be observed visible abrasion respectively fatigue and cracking trails, material-part peeling, degradation. Furthermore I considered the material deteriorated if I observed cutting, shear, deformation respectively material flow at the clamping.

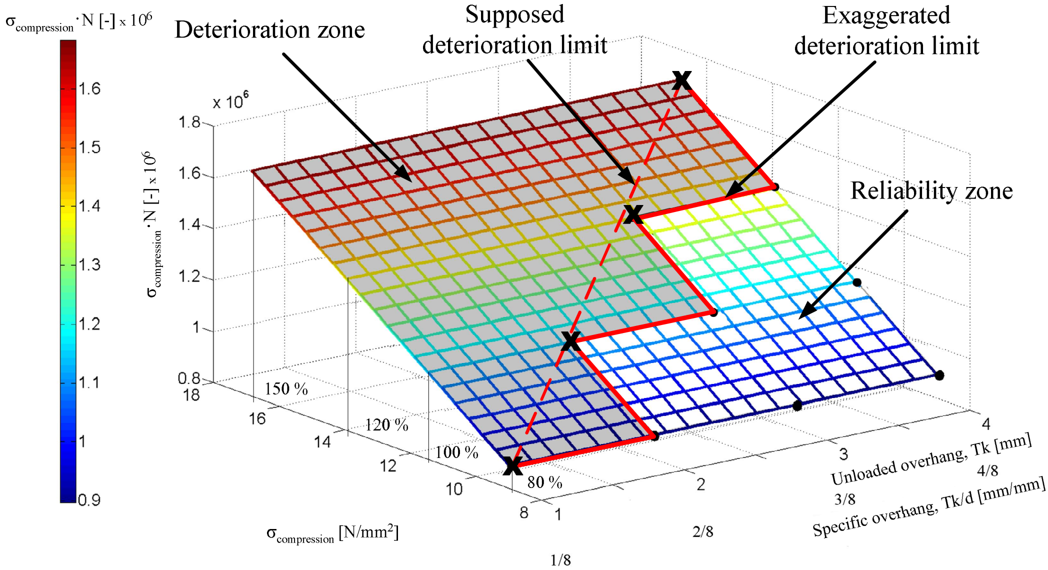
The character the appearance, the starting place of the deterioration formed totally rhapsodically during the tests. Deterioration appeared at the side of specimen at the clamping unit, at the edge of sole, on the sole in form of peeling. I couldn't establish the trends concerning the deterioration among the materials tested.

I couldn't show temperature change with measuring at my tests.

I completed one-one 3D-al figure at materials for the sake of better survey of results and for drawing conclusion (Figure 3.7). I presented the main characteristic parameters of the test on the diagram of the specimen:

- unloaded- specific overhang of specimen;
- load magnitude ($\sigma_{compression}$);
- the product of the load as well as the number of repeated load ($\sigma_{compression} \cdot N$).

With the help of these axises I presented the connected values in the space got. I matched a plane to the points presented. I set out the exaggerated and the supposed deterioration limit with the help of characteristic points and plane belonging to determination events. The exaggerated deterioration limit sets out the deterioration and the reliability zone from the plane surface.



X: measuring point showing the deterioration

●: point of rapid fatigue-test, without deterioration

Figure 3.7. Deterioration limit diagram of PUM 60A material

$$n = \frac{A_m}{A_t}$$

where: n : operation reliability;

A_m: area of reliability zone;

A_t: area of deterioration zone.

The Table 3.2. sums up the calculated value (n) of the operation reliabilities.

Table 3.2. Values of operation reliability

	PUM 60A	PUM 70A	PUA 90A
Operation reliability (n)	0,4	3,199	5,998

It can be established in totality that the operation reliability ratio is the more favourable at PUA 90A in case of materials tested. The PUM 60A shows the lowest reliability as n < 1.

3.6. Connection between the measuring results and the real load, repetition number (cycle number)

Beyond the normal force in vertical direction bending and also shear load are formed during the laboratory tests because of this the reduced stress has to be considered determining character. It has to be determined the reduced stress at given load level in the specimen for that the service-life character (parameter) of the silent-bloc manufactured from the tested material be determined from the measuring results. To determine this I had to applied again mechanical modelling. I presented the reduced stress got as a result in the function of the load number belonging to the real deterioration. I determined from the function matched to the prints and its equation the expected repeated number (cycle) of the endurable load by the basic material given, respectively I calculated from this the planned landing and take-off number.

3.7. The result of reconstruction development

1. I have established as a result concerning the tests of the machine-element (silent-bloc) of the small aircraft to be unambiguously the critical and not marked in the maintenance instruction that the PUM 60A material is not suggested to apply for elastic bed. However according to my calculation the service-life of the silent-bloc made from the material mentioned can be 3727 landings and take-offs.
2. The original material of the machine-element corresponds to the PUM 70A commercial product. I have established during my tests that higher service-life, number of cycles can be reached with the PUM 70A basic material than with the PUM 60A material. According to my tests the basic material further is also suitable to fulfil its task. From the test results however it can be concluded that the bed elastic part surely stands 3727 landings and take-offs. Thus at reaching the limit number determined the suspension of the landing shaft and itself the silent-bloc has to be checked whether the deterioration started or ensued. Such aggravation can come on with this suggestion to the new service system which increases the safety. Furthermore the insufficiency of the factory maintenance instruction can be supplied with this information.
3. The PUA 90A material is also suitable as a machine-element material. From the results of the tests is can be reached than with PUM 70A material.
4. Further development possibility: the circumspect engineering examination of the landing shaft operation reliability operation reliability operation reliability operation reliability operation reliability „weak point” and the available new up-to-date materials jointly can results technical development based on the service technical information module. The informations filled up into the system reach the manufacturer as the former system presentation also included that. The chapters worked out in the dissertation make

possible such technical development which doesn't involve constructional modification merely provides help to the aircraft users in everyday life. Based on my measuring a development involving construction modification also offer a possibility for a further step by jointly dealing with tribological (friction and abrasion between shaft surface and bush) and fatigue loads. Based on the results of FEM-examinations the Docapet TF- material (PETP/PTFE composite) showed proper strength against the given load. This composite paired with steel surface is known of its excellent frictional characteristics and its excellent abrasion resistance. Its Young's modulus of elasticity is near 2000 MPa, that is it far exceeds the elastomer PUR materials. Two-layer bed could be guaranteed with composite polymer and PUR (the PUA 90A can be suggested) joint application. A PETP/PTFE thin frictional ring could guarantee the adhesion-free, friction displacement of landing shaft which is surrounded from outside an elastic PUA 90A bush. That double ring takes place in a PET/PTFE could take up the friction effects. That solution - known the authority regulation - already is a factory-manufacturer powers but as a motivation, as a suggestion can get into the information system it can be the basis of further development.

4. NEW SCIENTIFIC RESULTS

1. I have worked out the method according to arranging principle “what, when, how is measured, and after who, what makes” to compare maintenance strategies with not uniform definition in the technical literature. Based on this I identified the maintenance system of small aircraft (Preventive Maintenance (PM) + Reactive Maintenance (RM)).

   1/a Taking into account the regulation of the competent aviation authorities: I have developed a new module system, which beside of the previous preventive maintenance (PM) and the reactive maintenance (RM) contains also some up - to - date elements of the risk based maintenance (RBM) and, condition based maintenance (CBM). It mixes in its methods and means the activity based on traditional written documentation with the information based, remote maintenance methods.

   1/b I have established that the suggestions of total quality management (TQM) and total productive maintenance (TPM) quality management and total operative systems can only be asserted in limited way at maintenance small aircraft. The method and means of TQM-systems can be represented is the new maintenance model with creating the technical information module.

2. I have worked out to the remote maintenance methods of the new maintenance system created for the small aircraft such a trouble-finder and preventing process in which it is defined the successive steps of trouble discovering and preventing.

3. I have worked out a measuring and evaluating system for the constructional development of the small aircraft which measures the real loads based on the vibration-acceleration then applied this calculates the stresses and deformations in FEM-system and based on all these construction model with laboratory measurings and evaluations the tribological and fatigue characteristics.

4. I have worked out the “section-matching” method for the numerical usefulness of the σ - ε function of elastomers with non-linear elastic material model tested. The process-with at least 95 % correlation - makes possible that the material models following to taste function be useful at FEM calculations. I established five typical sections (A, B, C, D, E) in case of PUM 60A, PUM 70A and PUA 90A.

$$\sigma_{material(i)} = m_i\varepsilon+b_i \qquad i = A, B, C, D, E$$

   I have determined the coefficients and constants of the section equation.

5. It can be established based on the vibration-acceleration measurings carried out in the phases of landing and take-off as well in the flying that six characteristic sections can be separated concerning the load. I have established based on the values of frequency the repeated loads and the vibration-acceleration that the phase of deceleration and acceleration on grassy field is the critical concerning the fatigue of landing shaft bed, not the moment of landing (touch down).

6. I have worked out a measuring method to the laboratory fatigue-abrasion test of the PUR material used for the landing shaft elastic bed. Based on the rapid fatigue-abrasion tests:

6/a I have established connection between the operation reliability (n) of certain elastomers and Young's modulus of compressive elasticity of materials. The higher Young's modulus of compressive elasticity (E) resulted longer deterioration limit.

$$n = n(E)$$

$$n = \frac{A_m}{A_t}, \quad A_n = A_m(\sigma \cdot N; T_k / d)$$

where: n : operation reliability;

A_m: area of reliability zone;

A_t: area of deterioration zone.

I created such 3D-al deteriorating diagram to interpret A_m and A_t which represents the „deteriorated" or „non-deteriorated" measuring points between the connection of the changing stress level ($\sigma_{compression}$), the unloaded overhang of the specimen and the „$\sigma_{compression} \cdot N$" product (where N is the number of repetition).

According to the testing system:

	PUM 60A	PUM 70A	PUA 90A
Operation reliability (n)	0,4	3,199	5,998

6/b The increasing modules of elasticity the fatigue are not characteristic to the place and mode of determination, regularity couldn't be established.

5. CONCLUSIONS, SUGGESTIONS

During my research-work I have surveyed briefly the general maintenance strategies according to their development.

I have created the „what, where, how is measured, and after who, what makes" series of questions and the answers belonging to it for each philosophy with the help of connections found during systemizing of maintenance strategies. The systemizing helps the daily user to choose early the most suitable strategy to be needed a certain application.

After surveying the activities and processes connected to the maintenance of small aircrafts I saw it reasonable to create a new maintenance model. This model mixes the traditional maintenance activity and the satisfaction of the users wide-ranging demands (for example: booking system, flight date etc.). Within the maintenance activities I have determined a trouble-finder and preventing processes in the remote maintenance module. This process can help for the maintenance men, repair men to carry out their operations. The supplemental technical information module can afford for the users, manufactures and engineers to clear away the possible emerging problems. Beyond all of these the maintenance model affords proper theoretical basis to complete a software by which the fixed in the module become suitable for everyday use.

I have worked out a reconstructional process within the supplemental technical information module concerning the elastic bed of the returning broken down landing shaft of the small aircraft, and regarding the bed no kind of information can be found in the maintenance instructions. Is a result of the process I set up an order of rank among the cast polyurethanes tested. The order of rank expresses the operation reliability of materials.

I have accomplished a 3D-al diagram knowing the test parameters and results from which it can be determined the reliability as well as the deterioration limit of the polyurethane materials tested to given applications.

I have determined the connection between the test results as well as the number of landings and take-offs (grassy filed, average conditions). Based on the model tests I have established that limit number which the silent-bloc made of given basic material surely endures.

As a result of the reconstruction development I have initiated maintenance aggravation concerning the elastic bed of the attachment of pipe cross-sectional landing shaft for the Cessna 172-type small aircraft.

Possibility of further step:

I suggest as a further step repeating the laboratory tests at different temperature ranges. It could be expressible interesting result of tests carried out at negative temperature range.

6. SUMMARY

I have made clear in my dissertation which ideas are belong to the machine maintenance and certain sources of literature what understand concerning those.

The technical literature mentions several types of the service strategies (philosophy). These are described generally in the sequence of their development, appearance. I characterized the certain strategies separately, then I have produced a summarized strategy-development figure. I have accomplished the comparison of certain philosophies with the question series “what, when, how is measured and after this who, what makes”. This system provides a possibility to make difference unambiguously between certain strategies.

I have surveyed the service the methods and the processes characterizing small aircraft. I have revealed shortcomings and developing possibilities in this. I perceived motive to develop the service system concerning small aircrafts in order to increase the aviation safety as well as to improve the quality of technical and using services. As a result of this I have created “the developed model of the small aircraft service system”. The model has got modular structure. I defined the exact containing elements of certain modules, furthermore I determined the sphere of the system users. I destined authorization for the user’s base on that the inspection of containing elements can be defined. The model developed provides theoretical basis for a software development connected to the theme, too.

The complementary technical information module got place in the module which detailed explanation I showed through on a reconstruction process. I have chosen a weak point of a small aircraft which was a broken elastic seating of main landing spring. Concerning the elastic seating there is no manufacturer reference in the service description.

I have determined the material of the original silent-bloc as a first step of the reconstruction process then I have chosen material with similar properties for the further tests.

As a further step of the test I have determined the mechanical properties of the materials. I have carried out tensile- and compression tests then I have evaluated the results. I have worked out a “section-matching” method evaluating the results of the compression tests. The method is suitable to use a σ - ε non linear diagram, characterizing an elastomer material, as a material model of mechanical finite-element (FEM) simulation programs.

I have worked out a measuring system to measure the vibration-acceleration rising in the main landing spring of the small aircraft airframe.

I have carried out the measures in real conditions. At evaluating the measures I took for a basis the length of time of landing and take-off. I divided to six typical sections that measuring range, to which I performed the Fourier analysis. After evaluation I determined the characteristic vibration-accelerations and their frequency values. Using the results of material tests and real time acceleration measures I have completed the mechanical finite-element model of the structure. I have determined the rising stresses and deformations at the elastic seating of the main landing spring.

To measure the deterioration during the machine-element tests I have made an equipment capable to laboratory fatigue-abrasion tests. The results of the finite-element simulations and of the real time measures can be set on the testing equipment. I have carried out fatigue-abrasion tests with the basic materials tested. I could set a reliability classification between basic materials on the base of test results. I have plotted a 3D-diagram giving the service life of the basic material at given test parameters.

As result of the process I have set up an operational reliability rate between the elastomers tested.

I have determined a connection between the test results and the real repetition number. I have established with this the limit number to be endured certainly by the silent-bloc made of the given basic material.

As the results of the reconstruction worked out in the technical information module I suggested service aggravation to ensure the advance of flight safety.

Based on my tests I have drawn up my new scientific results, further more I have made proposals for practical utilization of the results reached and to carry out further research tasks.

7. PUBLICATIONS IN CONNECTION WITH THE THEME OF DOCTORAL DISSERTATION

Periodical articles:

- Articles in foreign language:

1. **Lefánti R.**, Keresztes R., Kalácska G.: Plastic machine elements of small airplane: examination of the landing-gear leg support of Cessna 172. Journal of Scientific Bulletin: Serie C, Volume II. Fascicle: Mechanics, Tribology, Machine Manufacturing Technology, 2007. pp. 389 - 395.
2. Keresztes R., Zsidai L., Kalácska G., Andó M., **Lefánti R.**: Friction of polimer/steel gear pairs. R & D Mechanical Engineering Letters, 2008. pp. 97 - 106.
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