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INVESTIGATIONS ON LANDING GEAR SHOCK ABSORBER ACTIVE FORCE CONTROL

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Abstract

Energy dissipation during touch down phase of landing process is one of the key safety and design areas in aviation. Safety is the crucial factor in order to provide optimal landing of the aircraft, which reflects on a crew, passengers well-being and cargo safety. In the overall design of the aircraft, proper landing energy dissipation is the factor reflecting on the toughness of the structural mounts of the landing gears, which is connected to their weight and to the structural integrity of the fuselage itself. Well optimized landing energy dissipation reflects on forces acting on landing gear mounts lowering them due to the lowering fuselage fatigue level and extension its lifespan.

The only way of adjusting forces in the landing gear is to control the shock absorber behaviour. In case of the most common gas-fluid shock absorbers, it can be achieved by controlling fluid flow inside the shock absorber. It can be done by several methods, starting from hydraulic fluid viscosity change, finishing with mechanical flow damping of the fluid.

In this paper, authors describe physical phenomena related to the hydraulic flow based force control. They also describe possible ways of direct flow control inside the shock absorber in order to achieve desired force adjustment effect.

Keywords: landing gear, shock absorber, force measurement, active control

1. Introduction

Typically, landing gear shock absorbers are designed as passive devices with characteristics adjusted to the highest permissible impact loads [8]. The most common – and the cheapest – solution is to use the fixed orifice which allows restricted flow of the hydraulic fluid between two chambers inside the shock absorber. Diameter of the orifice is defined by the initial calculations during shock absorber design and optimized in laboratory tests in most cases only for limit energy and loads. However, in many cases the variation of real working conditions is so high, that the classically designed passive shock absorber does not perform well enough.

In contrast to the passive systems, the active solution of energy dissipating and loads adjustment can solve the problem of one point optimization extending it to the wide range of the conditions. Active force control can be achieved by applying number of sensors recognizing the type of landing (impact forces/loads) and via control system activating energy absorbing components in order to guarantee optimal dissipation of impact energy.

The active force control can be applied only when proper physical phenomena are identified, analysed and described as well as technical solutions are properly introduced.

2. Active Shock Absorber Characteristic Control Principle

Landing gear shock absorber's main function is to reduce loads (forces) acting on the aircraft fuselage during landing. There are other functions not so important but quite useful, for example reducing the vibrations when aircraft is taxiing especially on not paved and not flat runaways or/and taxiing roads which leads to improvement both passengers and cargo comfort of travel. During landing most crucial moment occurs when landing gear touches the ground and deflects (in most of the cases this is the first of number of landing gear deflections), all loads from the landing are about to be transferred to the fuselage – the loads are the result of aircraft hitting the ground with both vertical and horizontal velocities (horizontal mostly) [1]. If there was no shock absorption, landing energy would be transferred to the fuselage and very high peak loads would act on it. In order to reduce the loads transferred to the fuselage, shock absorbers are used for converting the landing energy in order to achieve as small loads as possible on the dissipation travel (landing gear deflection). The operation principle of the shock absorber is to move the volume of hydraulic fluid against the pressurized volume of gas causing the work of fluid (Figure 1), which requires energy from the landing process [2]. To make the process more effective, the fluid is pushed thru the orifices making the movement harder and resulting in more fluid's work on the same travel by increasing the resistance of the flow.

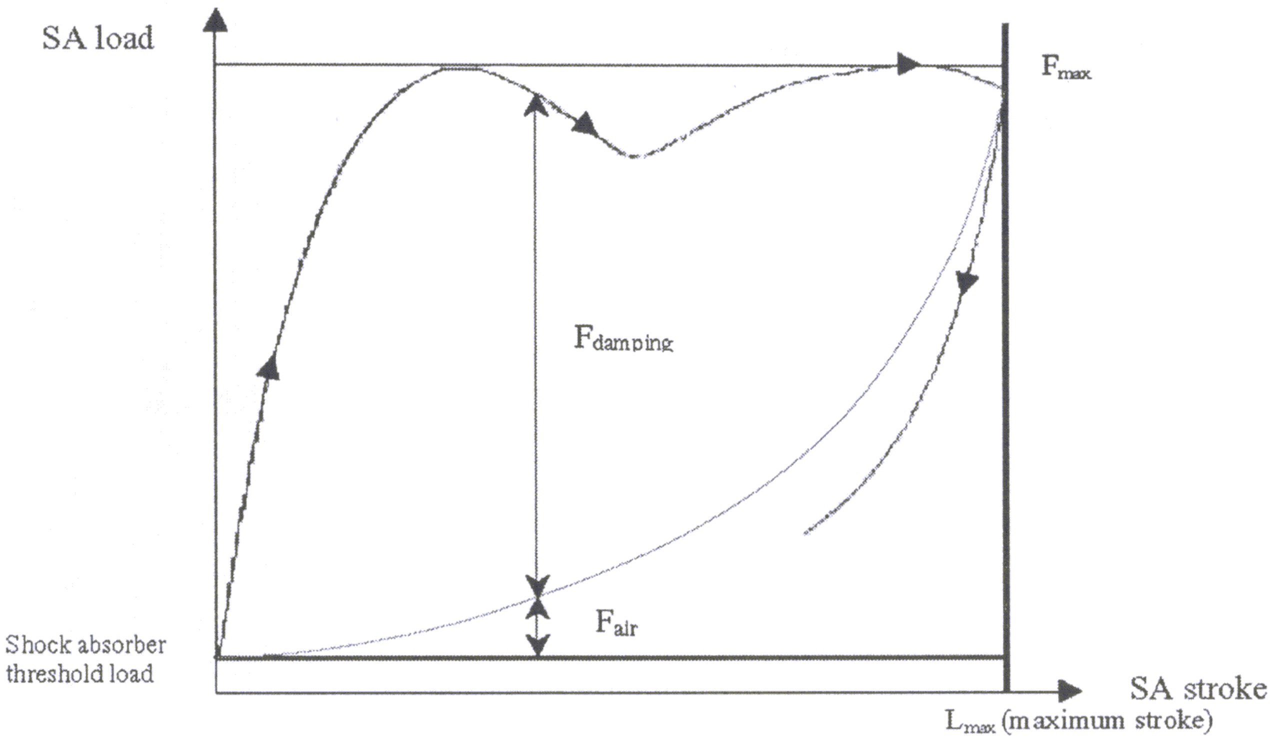

Figure 1 – Example of shock absorber load versus stroke characteristic. [7]

In order to achieve optimal characteristic of the energy dissipation the efficiency of the process should be a 100% (Figure 2) resulting in the constant resistance of the flow on the full travel of the fluid (this gives the constant force acting on the fuselage). Unfortunately, this is only the theory and most of the shock absorbers are not even close to this efficiency having it around 60 up to 75% (Figure 3). The efficiency of landing gear is calculated as the ratio of the real total work area (Figure 3) and theoretical or ideal one (Figure 2).

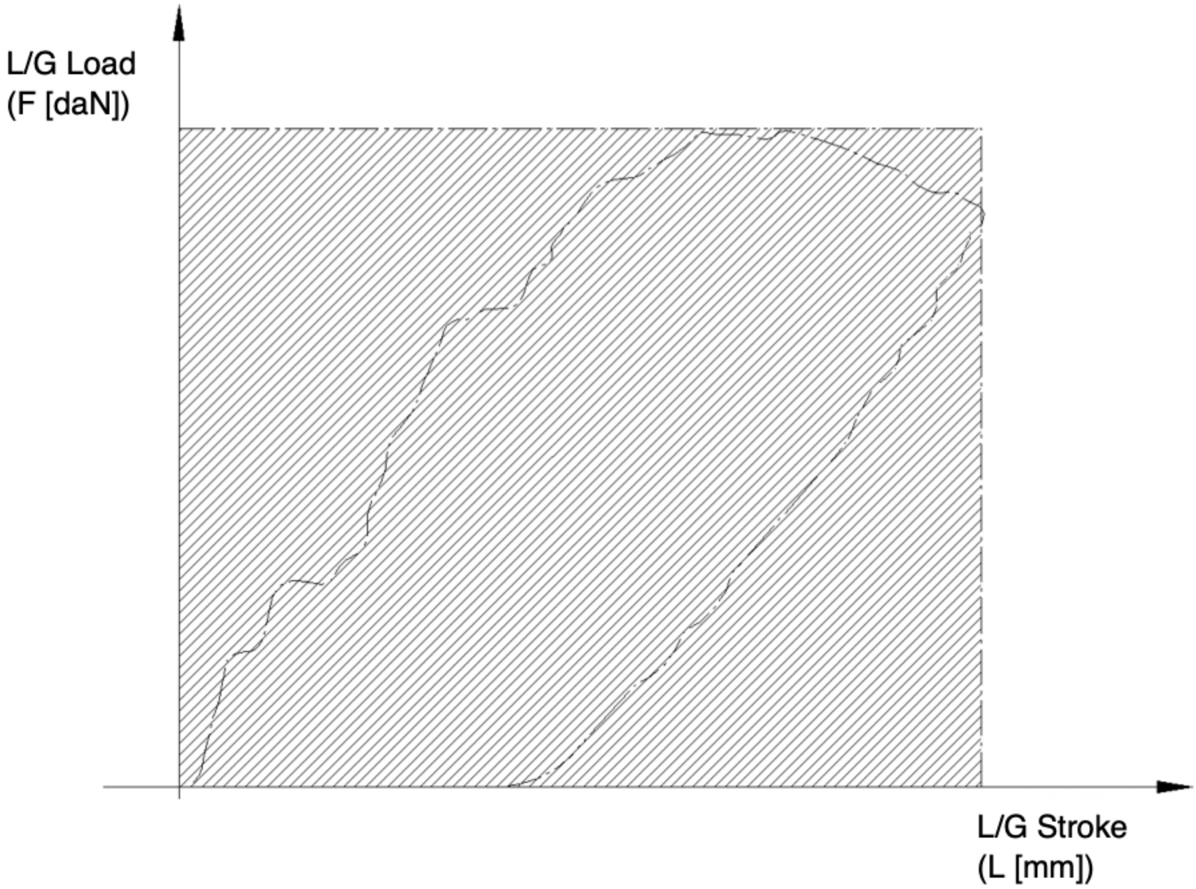

Figure 2 – Ideal (theoretical) Landing Gear efficiency – 100%. Source Ł-ILot

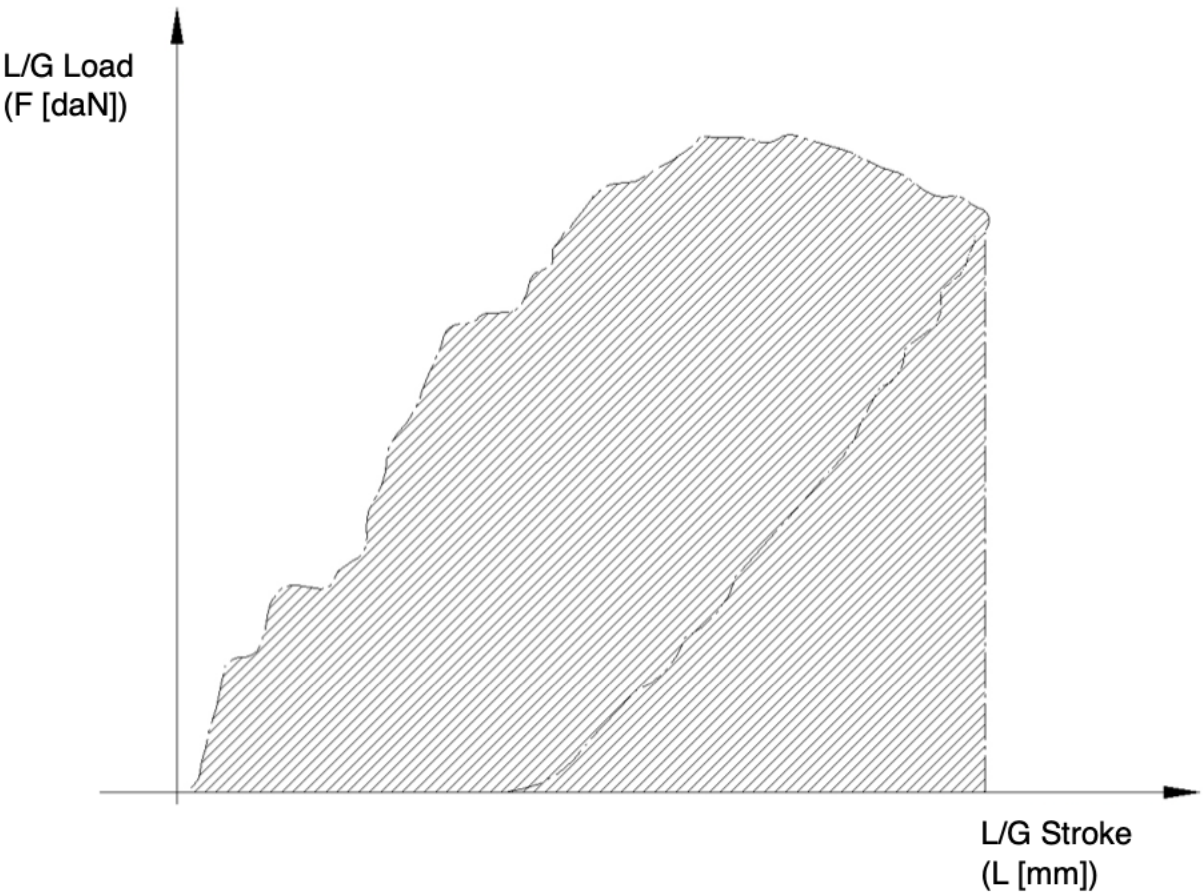

Figure 3 – Exemplary real life Landing Gear efficiency – 71%. Source Ł-ILot

This kind of behaviour is mostly owed by the fixed orifices inside of the shock absorber during whole damping process causing the optimal flow/resistance only in one point of the characteristic. Some designs exist where a number of different diameter orifices are used in order to achieve more than one optimal point but still, the efficiency is way below 100%.

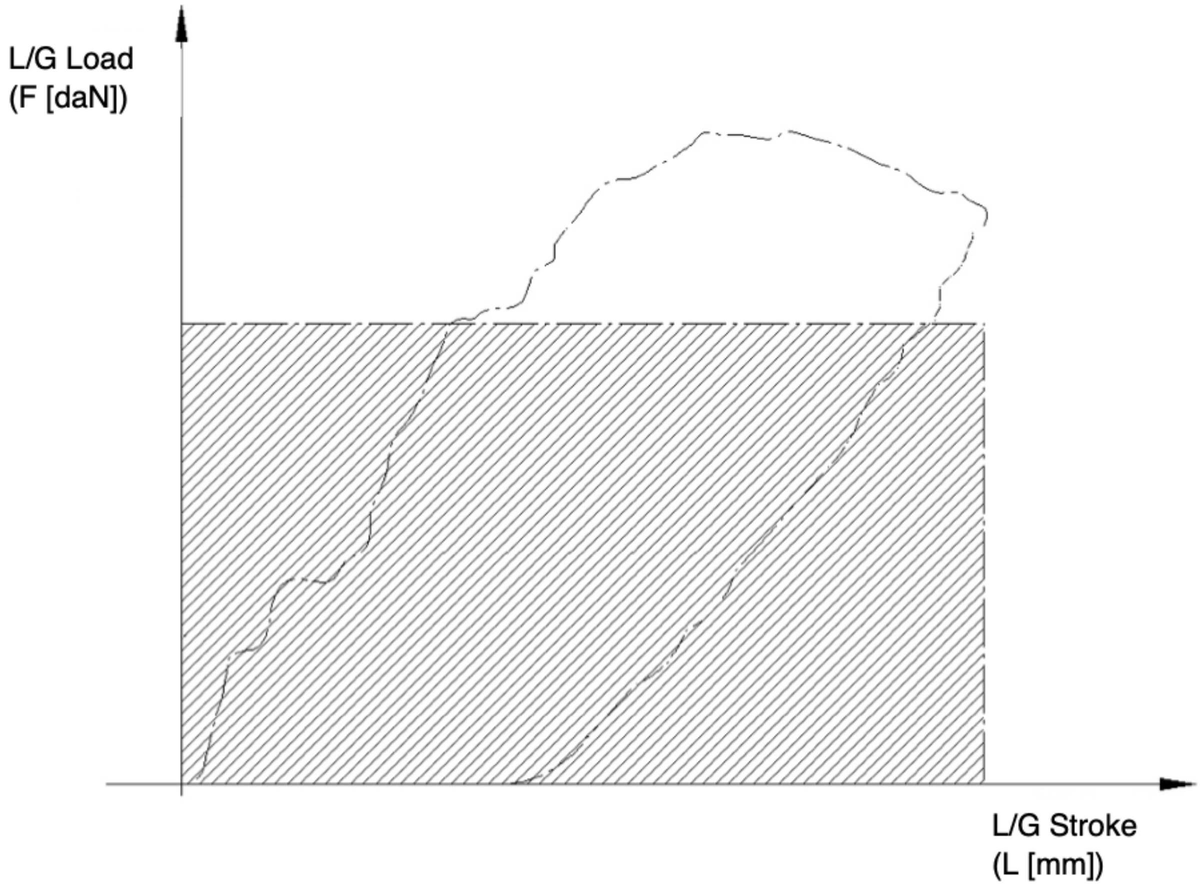

Figure 4 – Designed shock absorber work. Source Ł-ILot

In order to reach the close-to-prefect efficiency, it is necessary to be able to change the flow of the fluid accordingly to the deflection (and pressure rise) to maintain constant resistance through the whole damping process. When this is achieved not only efficiency rises up to 100% but also the loads fall as well (Figure 4) for the energy level as in Figure 3.
In the reality it is not possible to achieve the 100% of efficiency due to the number of phenomena occurring in damping process, which are not only dependent on the orifice area. The method of the improving the damping efficiency is to create more flow resistance at the beginning of the process and after achieving the desired deflection changing the flow resistance in order to maintain desired load level through the rest of the damping process (Figure 5). In reality, the achievable reduction in force is to create enough flow resistance in shock absorber in order to achieve as steep as possible force rise (red dotted line). Due to the number of phenomena occurring in real landing gear optimal achievable force rise characteristic (black dotted line). Area A between line and the current characteristic is equal to the area B, which is part of current landing gear characteristic. By achieving force rise along the black line work from area B should be transferred to the area A resulting in the decrease of forces (loads) acting on landing gear mounting points to the desired level.

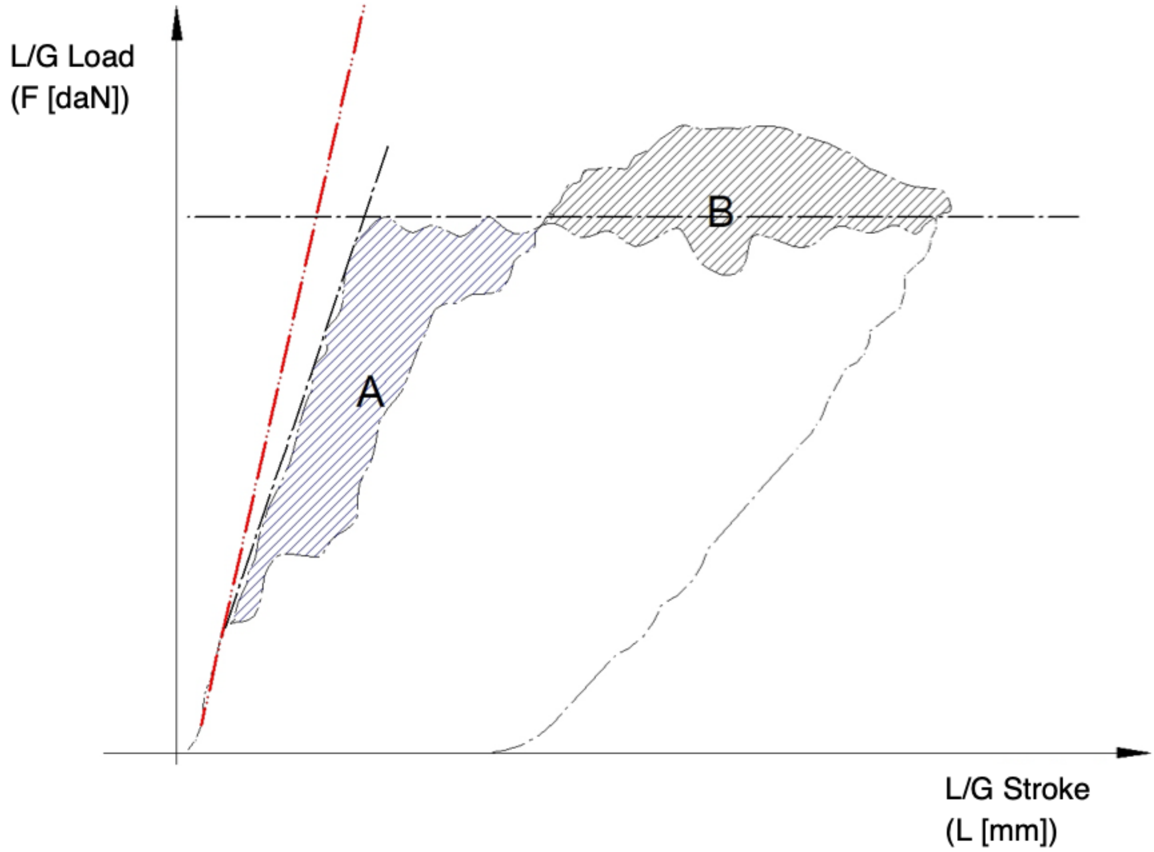

Figure 5 – Expected adaptive landing gear characteristic F=f(L). Source Ł-ILot

3. Flow control means (internal)

Damping/flow control inside shock absorber can be achieved by:
Controllable liquids:

- Magnetorheological fluids (MRF) controlled by magnetic field.
- Electrorheological fluids (ERF) controlled by electric field – not suitable for landing gears due to the nature of control. High current electrical fields must be applied in order to control it.

Controllable valves:

- Mechanical valves where actuation is performed by mechanical actuators in example trapezoid screws – not suitable for landing gears due to the speed and response restrictions. Mechanical solutions are too slow compared to the dynamics of the landing process.
- Piezo-valves where actuation is performed by piezo crystal based actuators.

Based on the experience gained by the authors in previous projects two of the solutions can be taken into the account flow control in the landing gear:

1. Magnetorheological fluids (MRF) [4] qualified as smart materials, which are controlled by magnetic field. Every MRF is composed out of two fractions: liquid and solid. Liquid fraction is in general synthetic or natural oil, which is responsible for MRF density when the magnetic field is not applied. Solid fraction of MRF is composed out of the particles of ferromagnetic material in different sizes and different susceptibility to the magnetic field. Both fractions are mixed together to get desired MRF properties. The change of the MRF properties is basically the change of the solid fraction particles arrangement in surrounding liquid. When no magnetic field is applied, the particles of the solid fraction are arranged randomly in liquid fraction. When the magnetic field is applied particles arrange (or try to arrange) according to lines of the magnetic field creating long chains (Figure 6). This results in the increase of density and shear strength.

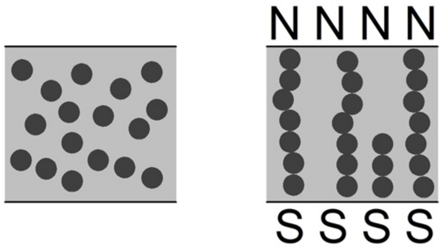

Figure 6 – Pattern of the magnetic field influence on the MRF. Dots represents ferromagnetic particles, background represents fluid. [3]

The flow control with the use of MRF can be achieved by changing the density of the substance or by grouping the solid fraction particles around the source of the magnetic field creating orifice for the liquid fraction to flow.
Downsides of the MRF as flow control mode are MRF's tendency to sedimentation due to its composition (the mixture of oil and ferromagnetic particles) what makes the control of the MRF quite challenging. Also, the weight of the MRF (which is heavier than pure hydraulic fluid) is the issue in the aviation application in comparison to the possible gain from the flow control. The solution (Figure 7) was tested by the authors in ADLAND project of smart shock absorber being a limited success [5].

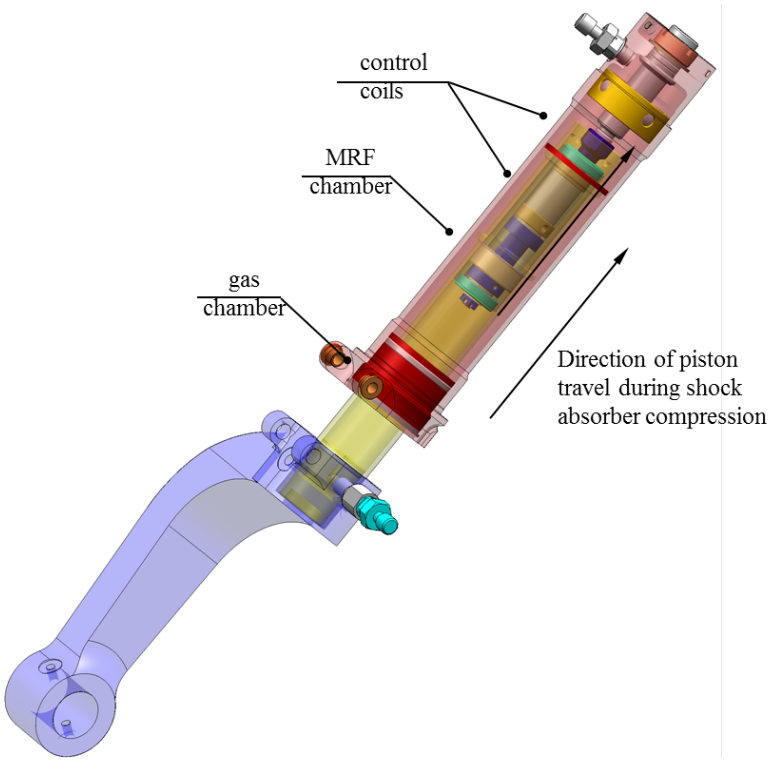

Figure 7 – MRF based shock absorber (ADLAND project). Source Ł-ILot

2. The second and the most effective solution for flow control is piezo-actuated control valve. This solution is compact and quick enough to control properly flow of hydraulic liquid inside the shock absorber limited space.
The solution utilizes standard hydraulic fluid as working medium but instead of fixed damping orifice, there is servo valve which can open and close fluid flow. The base for servo valve is piezo crystal based actuator which can expand or shorten when the electric charge is applied. Piezo crystals are mostly used as speakers or microphones in cellular phones because they can vibrate with high frequencies like a standard speaker being much smaller. Piezo crystals are also used in sonars when very high frequencies must be created in order to locate underwater objects or in precise positioning of the reflective and solar panels in the space applications (e.g., Cedrat Technologies CTEC DTT60S-SG with a SiC mirror Point Ahead Mechanism (PAM30) [9]).

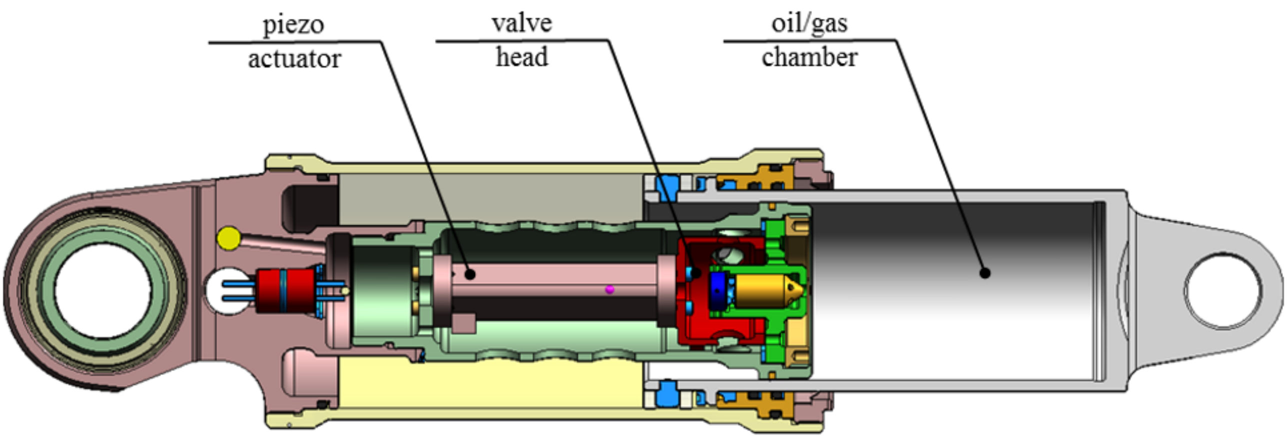

Figure 8 – Piezo-valve based shock absorber (ADLAND project). Source Ł-ILot

Unfortunately, piezo crystals can deform only a few percent so relative stroke of the valve is very little but enough to make variable damping orifice in range needed to perform correct damping for the designed shock absorber. The response of the piezo crystal based valve is quick enough (typically more than 100Hz) that can not only cover dynamics of the landing but also make possible to have several cycles of control in the process. Due to the operating principle and characteristic, piezo crystal actuators also enable very small movement increments as well as precise positioning The solution (Figure 8) was successfully tested by the authors in the ADLAND project and became the first choice for next projects [3].

4. Proposed types of flow control logic.

There are three possible methods of control logic of the hydraulic flow control:

1. Fixed characteristics of damping – one set of orifice dimensions (diameter, height etc.) is fed to the control system module. The control module can be a programmable computer/controller or a fixed hardware-based logic system composed out of logical gates and other discrete logic components. In this control scenario, during landing phase damping characteristic is simply executed by powering the logic system which executes fixed program. There is no need of using any other hardware – e.g., sensors - in order to aid the control system or having any feedback at all. This type of control system allows to operate in two modes:

- Without powered/executed control system. In this case damping characteristic relies only on mechanical systems built into the shock absorber – passive damping. This works also as a safety feature by allowing the shock absorber to operate on certain level which is secure – won't result in damage – for the aircraft and passengers but is far from optimal in operating conditions.
- With powered/executed control system. In this case damping characteristic is defined in the logic of the control system. The performance is better optimized but only for one – most common – landing scenario. The damping characteristic can be changed for another one without any or with minor changes to the shock absorber hardware only by changing the program or the fixed logic board.

Main advantage of the fixed characteristic control method is the straightforwardness of the system, but there are only two damping characteristics available – passive and active-fixed – so the energy absorption process is far from optimal. In most of the cases – when there is no plan of frequent change in the damping characteristic – this can be achieved by using standard and well optimized hydraulic shock absorber.

2. Multiple characteristic damping (semi-adaptive method) – several damping characteristics/scenarios optimized for different landing scenarios are fed to the control module. Control system itself is more complicated than in the first method because it has to act as a databank for several characteristics and has to enable execution of the right one. This can be achieved by onboard computer/avionics system which is triggered by the control signals based on existing

instrumentation such as velocity measurement. There is no need to install any external flight condition measurement systems or sensors. The external sensors can be installed in order to achieve more accuracy of landing scenario selection but this in not critical at this point. Semi-adaptive control system is better optimized than the fixed one due to the fact of having more landing scenarios, but the limitation of the semi-adaptive system is the number of scenarios. Too many can cause efficiency problems due to too many scenario selection "decisions" made in short period of time which can jam the control system making it non-operational. For the best prediction performance, no more than ten scenarios should be taken into the account. The semi-adaptive system has to be equipped in the fail-safe passive mode as well as the fixed one.

3. Full adaptive mode which relies on constant feedback from the aircraft's avionics and external sensors to enable real time control of shock absorber characteristic. This type of control enables full optimization of energy dissipation based on actual landing conditions. The start of the execution of the control logic is automatic and is performed by onboard computer, based on the defined criteria. The rest of the process is carried on by the independent landing scenario control system. There are no fixed landing scenarios – all the damping parameters are calculated in real-time using the mathematical models embedded in the control logic using feedback from the sensors. In order to achieve optimized control, it is needed to provide a fast computer system for damping characteristic calculations and a set of high accuracy sensors which will measure parameters needed for calculations of the characteristic. In most cases critical sensors for control systems should be independent from airplane avionics due to the safety reasons (communication interferences, speeds, not enough accuracy, etc.). Still the aircraft avionics provides vital data that can be utilized in pre-landing calculations. The system is also equipped with the passive mode for safety reasons. Full adaptive system is the most accurate of all three systems described but it is also the most complicated and costly.

In all control methods the landing scenarios and the mathematical models should be based on the actual optimizations made in the laboratory tests.

The control methods described in this chapter should be considered as universal – they can fit a broad range of flow control applications. In the control case described in chapter 2 some remarks and alterations must be addressed:

- Due to the flow restriction at the beggining of the control it is necessary to have the safety device which relieves the pressure/force if the valve is jammed or the control system won't open it in correct time. Pressure cannot exceed designated level for limit energy – landing loads/forces must stay within safe limits.
- The control of the flow restriction is different for all the landing scenarions. It is directly correlated with loads/pressures and deflections of the shock absorbers. Beacuse of this, it is not safe to use the first (fixed) control scenario which in result gives little to no control over the damping process.
- The control process should rely on the sensors (e.g. pressures, deflections) intergrated to the shock absorber in every control scenario. The correct set of sensors ensures that the flow characteristic is correctly chosen and safe in view of the danger described in bullet point one.

Based on the cost, complexity of the system, and performance ratio, it can be assumed that semi-adaptive control system could be the most reasonable choice.

5. Summary

Theoretical analysis of the damping control in aviation shock absorber estimated possible 15% decrease of maximum theoretical force acting on fuselage (with the assumption of the same energy in both classical and adaptive shock absorber). The presented value is the highest and most optimistic one projected. It is necessary to remember that the landing gear tires, a backlash, and elastic deformations decrease the efficiency of a shock absorber therefore in reality the gain from active control can be smaller than estimated.

As the method of load decrease, the flow control of standard hydraulic liquid was selected due to the authors' previous experience with various solutions.

The next step is to design custom piezo-valve fitted to the existing shock absorbers along with control system and to test laboratory grade adaptive system in laboratory conditions [6] in order to check the correctness of created assumptions.

All the analyses described in this paper were made in the Landing Gear Laboratory and Landing Gear Department of Łukasiewicz Research Network – Institute of Aviation in Warsaw, Poland where the authors work on daily basis performing full range of the L/G tests, optimization and scientific research.

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