ADAPTIVE ENERGY ABSORBER FOR CRASHWORTHY HELICOPTER SEATS

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1 *Introduction*

Every year, hundreds of people sustain major injuries or die after a helicopter crash, despite the current technology of energy absorption seats. Existing energy absorption systems in helicopters or crashworthy seats in general, have fixed energy absorption profiles that are indiscriminate of the passenger weight and/or the crash velocity. It is when these parameters (passenger weight and crash velocity) are ignored, the energy of the crash is not absorbed efficiently. Sometimes even, the presence of the energy absorption system and its stiffness endangers the passenger.

With this in mind, an adaptive energy absorbing mechanism is designed to improve safety of the helicopter passenger by reducing the impact energy on the spine. This automatically adapts to the passenger's weight and size, to the impact velocity and the system must be installed in existing seats.

2 Mission need statement

Design an adaptive energy absorbing mechanism to improve the safety of the helicopter passenger by reducing the spine load. The system shall automatically adapt to the passenger's weight and size, to the impact velocity. The system must be installed in existing seats.

3 Requirements

The requirements for this project are:

- Comply with the mission appropriate requirements defined in MIL-S-85510 and Crash survival design guide.
- Force limitations on passenger.
- The energy absorber system has to be auto-adjustable to different passenger's weights (minimum weight adaptation value according to the 5th percentile female body mass of 51 kg, up to the maximum weight adaptation value according to the 95th percentile male body mass of 101 kg).
- The energy absorber system has to be auto-adjustable to a range of impact velocities (1.5 m/s to 14 m/s).
- The seat has to remain functional and adjustable for a various range of passenger body lengths (1.56 m to 1.96 m).

4 Simulation

To do a preliminary design of the magnetorheological damper it is necessary to get to know the forces that are needed to slow down the passenger. Therefore a simulation of the behaviour of the seat is made. The first step was to build a model (figure 4.1). The weight of the passenger and the suspended part of the seat are considered as a point mass.

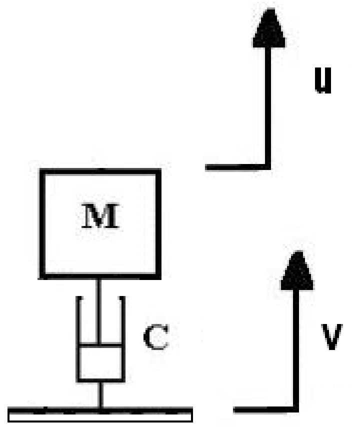

Figure 4.1: Simplified representation of the absorption system

The absorption system is represented as a damper with damping coefficient C. The damping coefficient is not constant, this to increase the efficiency of the system. At the bottom an impulse is placed which represents the crash. This impulse has a triangular shape which changes for different impact velocities as shown in figure 4.2.

As this was finished, the model was solved numerically using Matlab. It was chosen to change the damping coefficient three times during the simulation to reduce the time needed to analyze the results. However, in reality the damper is able to change the damping coefficient every 6.5 ms. To optimize the system, the maximum stroke was set at 25 cm (meaning a 5 cm safety buffer) and the spinal loading has to be minimal. Investigation of the results shows that until an impact velocity of 9 m/s the spinal loading remains lower than 14.5 G (11 m/s to remain below 20 G). Results for the 50th percentile male are shown in table 4.1. These results are also representative for the entire range of passengers.

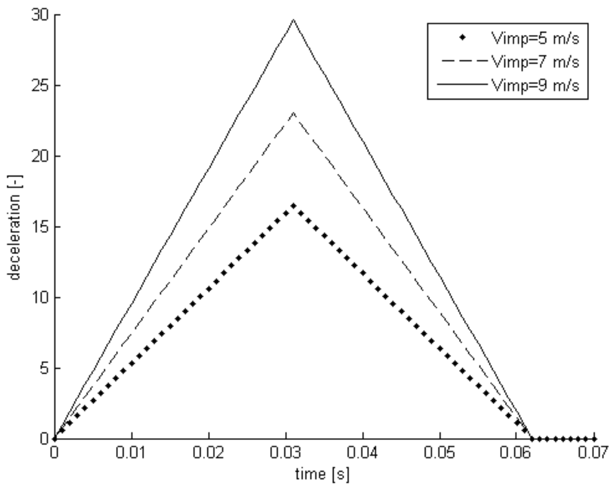

Figure 4.2: Simplified impact impulse at different impact velocities

Impact velocity [m/s]	Spine load [-]	Stroke [m]
6	8.3085	-0.2208
8	11.9484	-0.2482
10	16.7973	-0.2482
12	22.0019	-0.2467
14	27.4697	-0.2498

Table 4.1: Different spinal loads and stroke distances for various impact velocities

Investigation showed however that the system does not work very efficiently at the moment. This is because of the limited number of different damping coefficients. The higher the difference between two successive damping coefficients the higher the peak load on the passenger. At the moment the damping coefficient is also considered to change stepwise. This is not possible in reality and a simple simulation of this effect showed that the needed stroke will increase while the G-loads on the spine decrease. These results were put into a database that was used to size the damper.

5 Concept selection

Four concepts were made during the design. The first one is a friction based braking system. It uses a disc brake to decelerate the seat during a crash. The adaptation to different masses and velocities can be performed by changing the braking force. The main issues of this kind of system are the limited reaction speed and inaccuracies due to long term environmental influences.

The second design is a gas pressure energy absorbing system. It consists of a simple pressurized vessel (a cylinder) with a pressure loading that is tailored to the weight and the extrapolated crash impact velocity. Energy absorption is achieved by compressing the gas in a pressure vessel during the stroke, like a compressive stroke in a piston engine. It can be adapted using controlled valves, which depressurize the vessel. Due to a difficult control, inaccuracy of the build up pressure and the uncertainty concerning a long lifespan, the pressure system will be hard to implement in helicopter seats.

A third design makes use of the traditional plastic deformation to deal with the energy absorption. It has basically two devices which can adapt the system to the different cases. A wire is pulled through the system during the crash and will be deformed simultaneously by a wire bender. The first one is a brake system placed at a pulley where the wire is wounded on. The less friction this rotating pulley has, the less the wire will stretch and thus the less energy can be absorbed through the wire. The other one can be achieved by controlling the pressure exerted by the rollers on the wire. The problem of this system is the complexity, since it will be hard to calculate all parameters.

The last and definitely the most promising concept is the design with the magnetorheological damper. A magnetorheological (MR) damper works in the same manner as conventional dampers. It is composed of a tube filled with a fluid and a cylinder which can move along the tube. The movement of the cylinder is damped by the fluid in the tube. The difference with conventional dampers is that the characteristics of the damping can be changed by changing the characteristics of the MR fluid. This results in an active adaptive absorbing system. It combines a lot of features which are of interest in designing an adaptive absorbing helicopter seat. The whole absorbing system is concentrated in one device which is easily controllable by changing one parameter. A MR damper has a fast reaction speed and is very accurate which are both very important features concerning an adaptive helicopter seat. This concept is the best and will be designed in detail. In table 4.2, the trade-off table for the four concepts is given. Only the 4 most important criteria are stated.

	System complexity	Adaptation speed	Adaptation accuracy	Adaptability
Friction	-	-	--	+
Pressure	+	+	-	+
Plastic	--	-	-	-
Magnetorheological	+	+	++	+

Table 4.2: Trade-off table with the four most important criteria

6 MR Damper

This is the most innovative part of the design, as it absorbs the impact energy during crash. The magnetorheological or MR damper is filled with a MR fluid, which can be controlled by generating a magnetic field with an electromagnet. This allows the damping characteristics of the shock absorber to be continuously controlled by varying the input current. Furthermore the MR technology is already widely applied in various fields, such as seismic damper applications for buildings and semi-active vehicle suspensions.

For the fluid, which consists of iron particles, a carrying fluid and additives, the choice is made to take the MRX-140ND, which is commercially available by LORD Corporation. The selection is based on the excellent settling properties, a low friction coefficient and the proven application of this fluid.

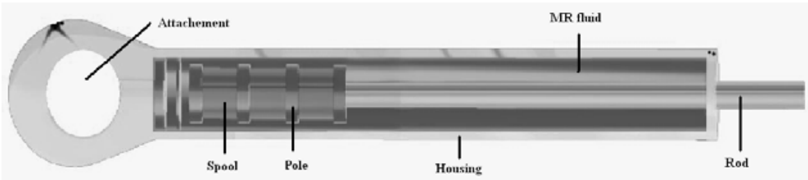

Figure 4.3: Cross section of the MR damper

Furthermore the damper consists of a moving piston, which on his turn consists of 3 spools and a rod (see figure 4.3 for the lay-out and dimensions of the damper). The spools are built of an iron core and a copper wire wounded around it. The iron core material amplifies the magnetic field that is generated in the spool and consequently reduces the required current. Between the housing and the piston is a gap where the fluid is then squeezed through in order to absorb the crash.

The geometry of the housing, containing the piston and the fluid, is designed such that the amount of MR fluid needed is minimized. This is because the fluid is the highest contributor to the cost and weight of the damper.
Now that the geometry is designed, it is important to establish a relation between the current required and the different damping coefficients required for the varying passenger masses and impact velocities.

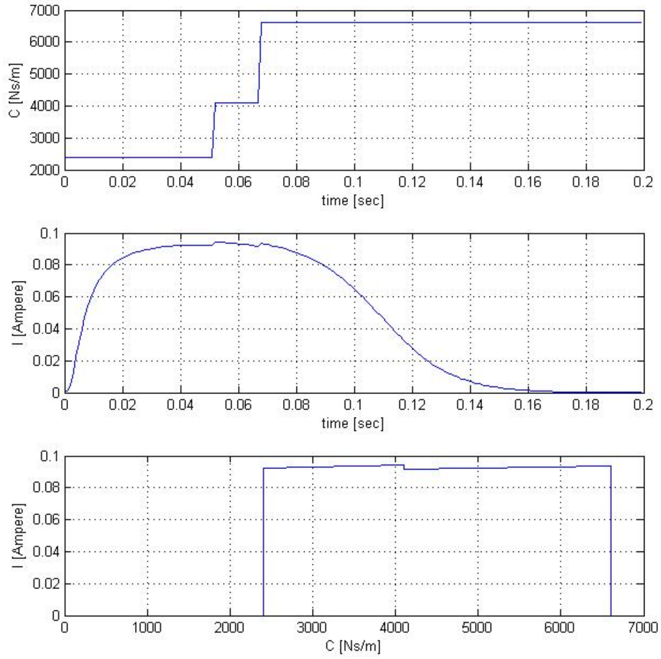

Figure 4.4: Required current for a series of damping coefficients

Figure 4.4 gives for a given series of damping coefficients the required current needed to alter the magnetic field for the total crash duration.

The main advantage is its very fast adaptation time of about 6.5 ms. Furthermore the damper will cost about 328 euro and will weigh about 5.5 kg. From the MATLAB simulation it is further concluded that a maximum current of 0.1 A is required for the damper, which can easily be supplied by the helicopter's battery.

7 Structural support

The structural part contains all the parts that support the seat and the absorption system. The most important components are the support columns, the joints between the MR damper and the support columns and between the seat and the support columns. During normal flight conditions the seat is connected to an aluminum plate which is mounted to the support columns (Figure 4.5 and figure 4.6). When a crash is detected the connections are released electronically by a pin retraction system. As a result the aluminum plate and seat will slide downwards along the support columns. In this situation the seat is only supported by the MR damper which will reduce the impact force.

Because of airworthiness regulations almost all structural parts are designed to withstand 20 G which corresponds to a force of 25 kN. Most of the parts are made of Al2014 which is needed to attain the necessary strength and to limit the weight of the structure. The total mass of the structure of the seat is 39 kg.

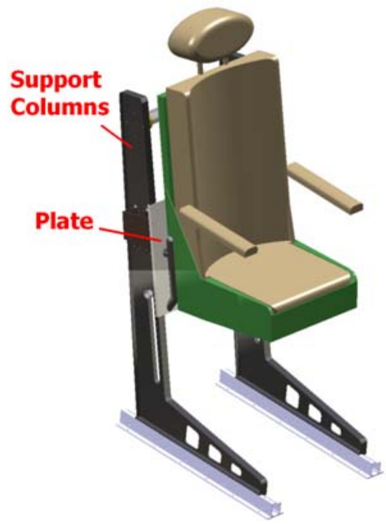

Figure 4.5: Front view of the seat

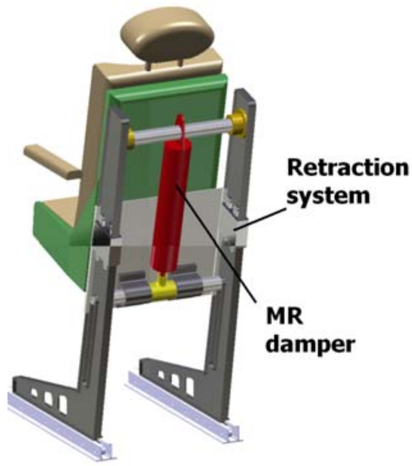

Figure 4.6: Back view of the seat

8 Sensors and control

To control the adaptive energy absorber system, a control software and hardware interface is needed. The control hardware consists of the sensors that measure the velocity of the helicopter, the altitude of the helicopter and the weight of the passenger. The information is incorporated into the control software to analyze the necessary energy absorption profile for the system, which is dependent on the crash velocity and the passenger weight. The energy absorption profile is given in terms of the damping coefficients for the damper. The damping coefficients vary in time during the crash.

Existing on board velocity sensors are used to measure the helicopters vertical downward speed. The height sensor is a dual proximity sensor used in cars with an accuracy of 1 cm. The weight sensor is also for measuring weights of seat passengers in cars. The two are used to improve airbag systems in the automotive industry – they are new in the industry.

The control software (the microprocessor) contains the database of the energy absorption profiles. It analyses the information fed by the sensors to detect the status of the helicopter. The weight of the passenger is recorded before flight. If the helicopter is crashing (when vertical decent velocity is greater than 4 m/s and the time to touch the ground is less than 0.2 s), the information from the sensors are used to select a damping profile. This is then transmitted into the amount of current that needs to be applied to the magnetorheological damper during the crash. The database contains 70 crash scenarios. Before crashing, the locking pins, that support the seat, are retracted and the seat is supported by the damper for the crash.

9 Conclusion and recommendations

To conclude, as stated before; the magnetorheological (MR) damper requires a maximum current of 0.1 A and a voltage of 12 V to adapt the damper to absorb the most critical crash energy cases and adapts in 6.5 ms. It weighs 5.5 kg and has a material cost of 328 euro.
The structural support of the seat weighs 39 kg. This mass includes the MR damper. It costs approximately 400 euro. The structure is made mainly of aluminum alloy (Al 2014).
In the simulation of the crash dynamics, the found damping coefficients could not all limit the G forces on the passenger below 20 G's. The crash dynamics were simulated using a single mass-damper model. From simulation, a time of 200 ms is needed to activate the energy absorption system.
The velocity measurements are done using existing on board velocity sensors. The height (proximity) and weight sensors are adapted from the automotive industry. They have accuracies of 1 cm and 0.1 kg, respectively. Their combined cost is 1500 euro.

As recommendation, the characteristic long term behavior of the MR damper must be further investigated. The settling properties of the MR fluid and its chemical reactivity should be investigated as well.
The structural weight of the whole design can be decreased. It is recommended that engineering tools like Finite Element Method (FEM) analysis should be done for material optimization, and thus optimization of the weight. Also, different cheaper and lighter materials can be used to substitute component parts of the current design.
Much better modeling of the crash dynamics is needed to improve the accuracy of the damping coefficients for the MR damper. As well, the database should be increased to more than 70 scenarios. The price of the height and weight sensors should be decreased by using other cheaper sensors that will provide the same performance qualities.