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DEVELOPMENT OF AN APPLIENCE FOR PROPERTY PROTECTION WITH A VIEW TO RELIABLE FUNCTIONING

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Abstract:
The aim of study is to develop a security appliance spraying lachrymatory substance at the moment of intrusion. Working principle has in advance been decided; it consists of twinned gas-holders pressed simultaneously by means of an electromotor-driven mechanism. The primary aspect of the development is enhancing the reliability of operation within changing environmental conditions, principally temperature, air humidity. This objective requires the use of tools and methods of quality management, such as fault and hazard analysis, Quality Function Deployment and product simulation. To help robust design planned experiments are being carried out both virtually and on physical prototypes. Computer models simulate the behaviour of the appliance to detect possible malfunctions resulting from external effects and/or lack of strength and rigidity. Results confirm the effectiveness of the joint use of quality management methods and computer simulation in product development. It is expected the final product will start and complete operation with high probability in case of alarm.

Keywords:
product development, quality management, simulation, reliability

INTRODUCTION

The main objective of the project is to develop a product idea to get a working product of reliable functioning. The product is a security system device the main function of which is to make an intruder harmless with gas discharge.

The problem is two-fold. In the one hand the product should, after a long time of rest in varying environmental conditions (temperature, air humidity, dust), be able to come into action immediately when needed. On the other hand, after it starts to operate it should continue until the end without intermission, even if there emerge some obstructive factors. In the course of solving these problems we develop a prototype starting from a preliminary design shown in Figure 1 below.

The objectives outlined call for tools and methods of appraisal of engineering characteristics, fault analysis, risk assessment and robust design. [1] [2]. In the present study we show how the use of these tools typical to quality management helps improving the reliability of operation of the security system appliance of given working principle.

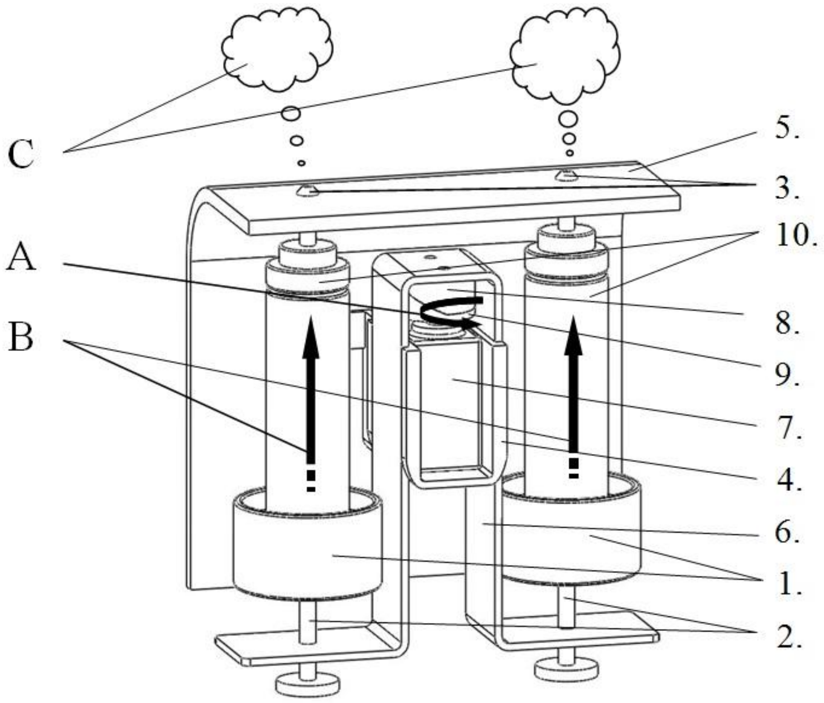


Figure 1: The security system product

Table 1: Product parts

Product mechanism and Parts		
A) Lifting mechanism	B) Gas bottle's moving	C) Gas

1) Bottle holder	2) Bottle holder's fixing screw
3) Nozzles	4) Motor holder
5) The case	6) Stirrup
7) Motor	8) Upper cylinder
9) Lower cylinder	10) Bottles

EXPERIMENTAL

We built our project on the subsequent application of Fault tree analysis based on design drawings, Failure Mode and Effect Analysis (FMEA) effected on the original design, Quality Function Deployment (QFD), repeated FMEA on design with modifications as well as a series of computer simulations of motion and strength behaviour of the planned assembly.

Fault-tree analysis, brainstorming

Analysing processes should never be performed alone. Every project needs a team to take advantage of brainstorming, so the job can be done more quickly, easier and with less bias.
On the starting team meeting we discussed which environmental factors can have an effect on the product. It was agreed that no such amount of dust is probable to get into the construction that can have an effect. The two factors that the team decided to get control of are the effect of humidity changes and the effect of temperature changes.
Constructional deficiencies can also lead to fail. To make this sure not to happen, we had to guess some previous operational and failure parameters. The first change in construction proposed was to make the connection between bottle holder and its supporting screw fixed. That way the axes of gas-holders will have less possibility to deviate from their right position. As regards materials to be used for the parts we came to the idea that everything will be made of PA type 6, except for the stirrup, which will be made of stainless steel.

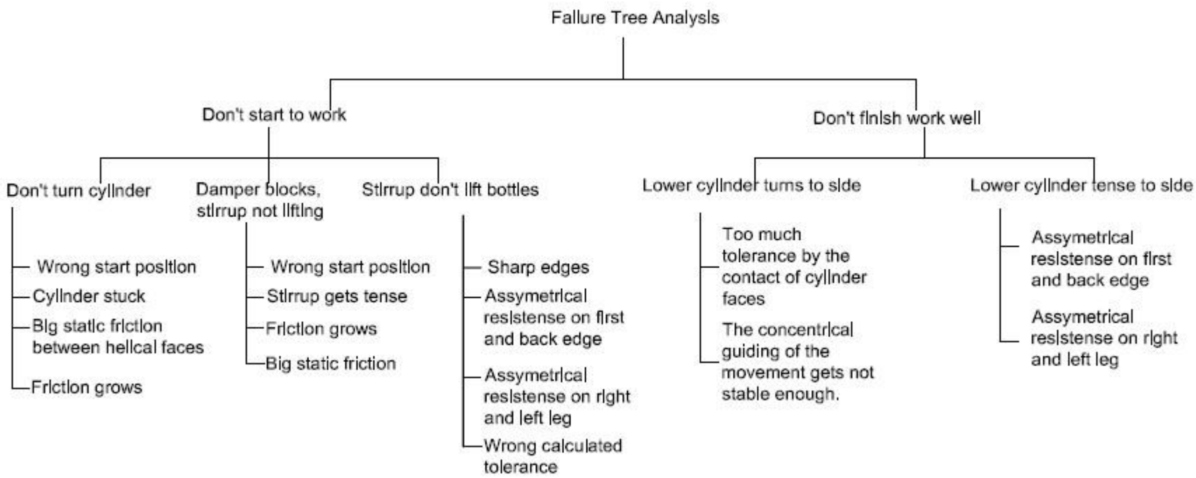


Figure 2: Failure Treeof the product

Graphical analysing methods

After mapping the possible failures and their relations, we continued with Failure Mode and Effect Analysis (FMEA) as shown in Figure 3. With this analysis we identified 4 chains of occurrences, consequences and detection efficiency that should get special attention:

- Bottle holder not holding bottles safely - Holder axle tilts - Assembly control (324)
- Bottle holder not holding bottles safely - Concentricity fails - Simulation test (180)
- Stirrup not guiding parallel moving - Asymmetrical resistance on two sides - Simulation (180)
- Nozzle cannot be pressed in - Nozzle jumps out of case - Prototype test (192)

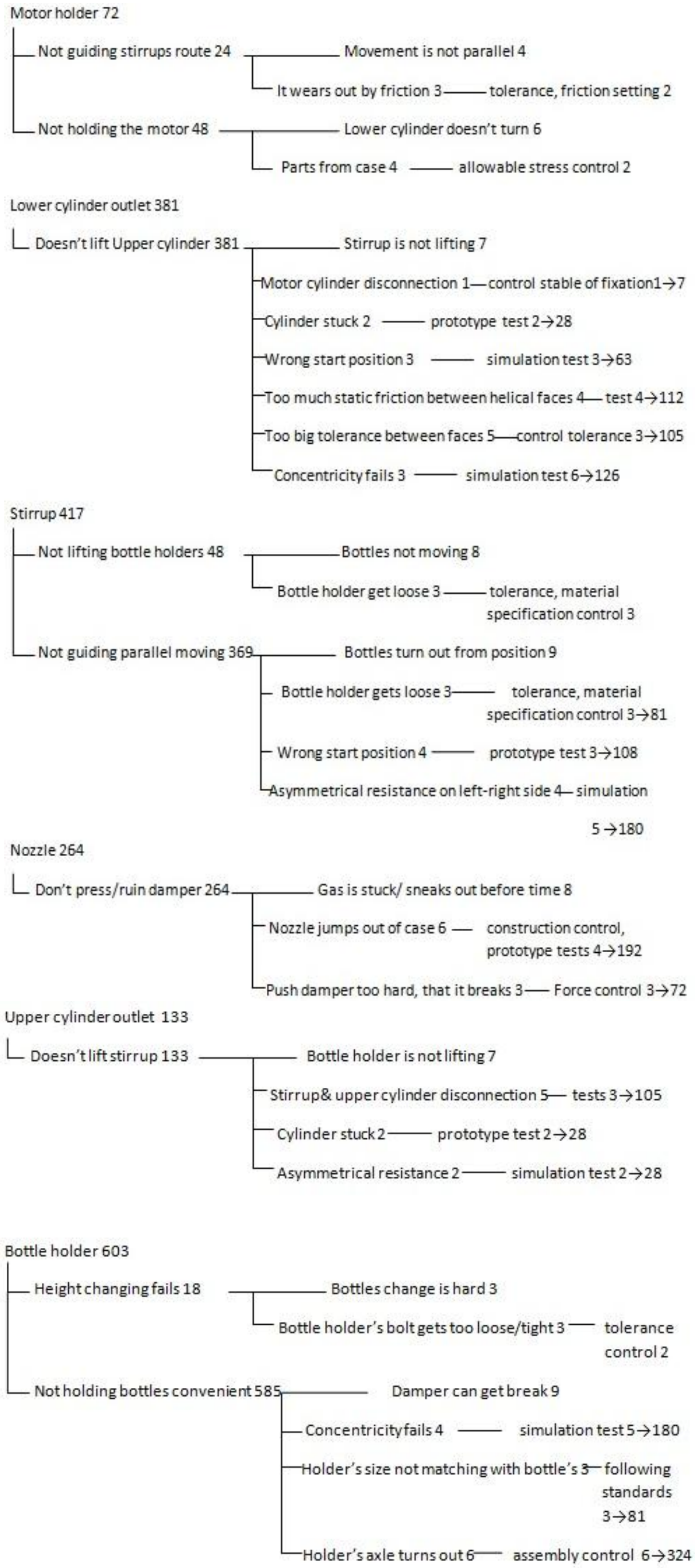
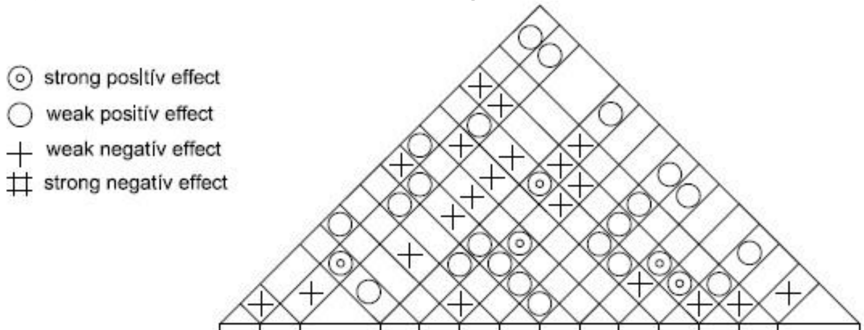


Figure 3: First FMEA Analysis

The findings of our FMEA exercise have further been confirmed by conducting Quality Function Deployment (QFD) the schema of which is shown in Figure 4.



	Importance	Friction between helical faces	Stirrup tolerance	Stirrup friction	Angle of movement	Motor Torque	Strenght of Nozzle fixation	Maintainability, refill	Product lifetime	Thread pitch of helical parts	Length of motor spindle	Width of stirrup	Supported length of stirrup	Distance of stirrup arms	Rigidity of stirrup
		—	—	↓	↓	—	↑	↑	↑	—	↓	↑	↓	↓	↑
Make Intruder harmless	5	◎			#	◎	○		○	◎	○	○	+	+	◎
Don't let out gas unnecessarly	2		◎		+				○	+					
Easy to refill	3				+			◎	○			○	○		
Come Into actIon when Its needed	4	+	○	◎	+	◎	◎	○		○		○	+		○
TechnIcal Parameter Importance		5	4	3	4	4	5	3	3	4	2	4	4	3	3
First product on market so nothing to compare with.															
Overall Importance		6	8	8	-19	18	13	10	10	12	5	12	-6	-5	14
Mesurement UnIt		μ	mm	μ	°	N/cm	N	min	y	mm	mm	mm	mm	mm	Nmm^2
Our product		0,07	0,3	0,28	0,01	4,1	40	15	3	3,4	35	30	104	24	4,2E+6
MInImum Value		0,05	0,1	0,05	0	3,5	38	5	3	2,5	30	25	90	20	1,8E+6
Maximum Value		0,2	0,4	0,2	0,01	5	55	15	5	3,4	35	45	104	30	8,8E+6
Target Value		0,07	0,3	0,28	0	4,5	50	10	4	3,4	35	40	95	20	5,6E+6
EffIcIency															
GeneraI Effect															

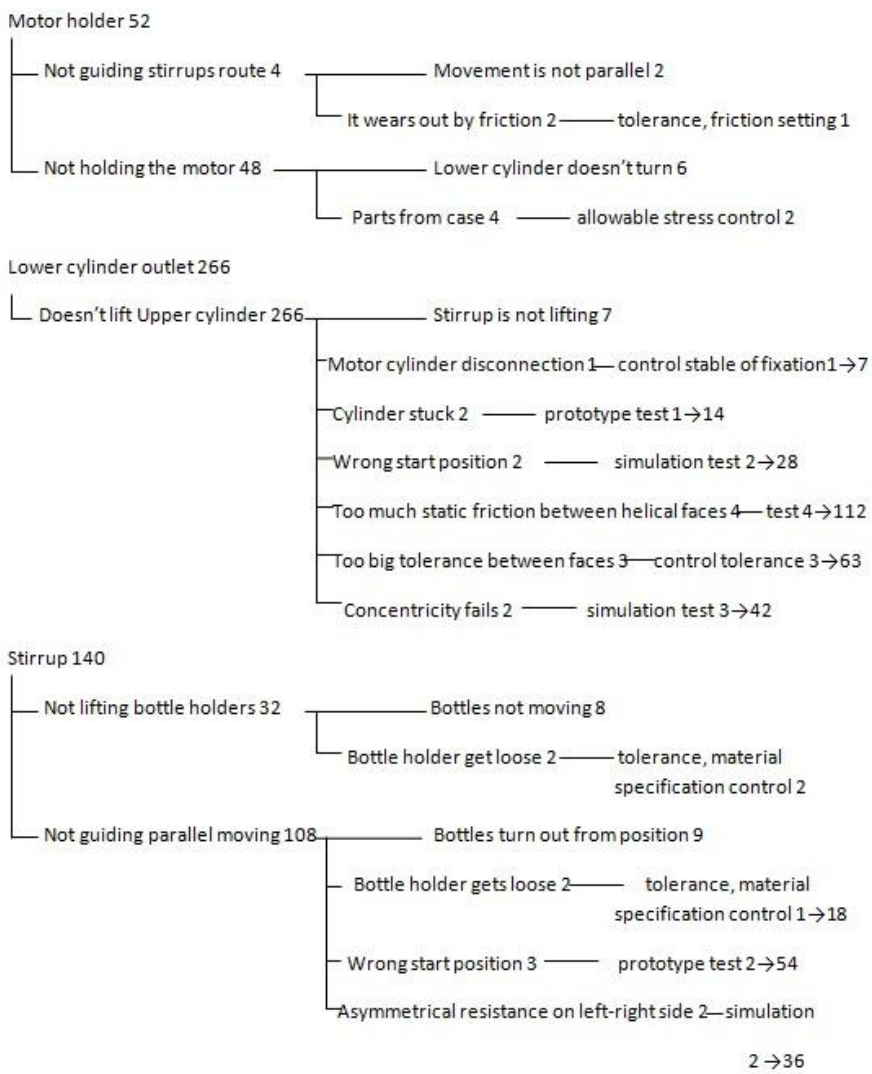
No concurent product on market to compare wIth.

Figure 4: QFD Analysis

The QFD analysis revealed that the tolerance of the angle of the movement as a technical parameter is the one that needs the most control. We should secure that the movement of the bottles is parallel, and the forces and resistance are symmetrical on both sides of the stirrup. It is important to have the right amount of motor torque, because it should lift the structure 3.3 mm high against 20 N resisting forces on both bottles. Angle of movement has also a strong relation to the tolerance of the stirrup. If the tolerance is larger than needed, the stirrup is able to turn left or right a little. By increasing the width of the stirrup we can also have a better affect.

By applying QFD's logics we could decide what changes we have to make to the construction. The nozzles should be fixed more, and its more secure if the stirrups length is as short as possible, its width as big as possible, with the right amount of friction. We have to take care for the stirrup weight too when changing its measures, because we have to be sure that the motor torque is sufficient to lift the weight and press in the nozzles to let the gas out. Indeed, the QFD analysis gave us a feeling on which technical parameters how significantly have to be modified. To find an optimum of them, however is left to the simulation studies.

Both the first the FMEA exercise and the QFD analysis point out that the product parts that have the highest potential danger to reliability are the bottle holder, the stirrup, and the nozzle. With modifications of the stirrup we have a strong positive effect on the bottle holders too. When we increase the rigidity of the stirrup, we have less possibility that the holders will turn or move out from position. After hypothesizing these proposed changes to the construction we conducted a new FMEA study that is summarized in figure 5.



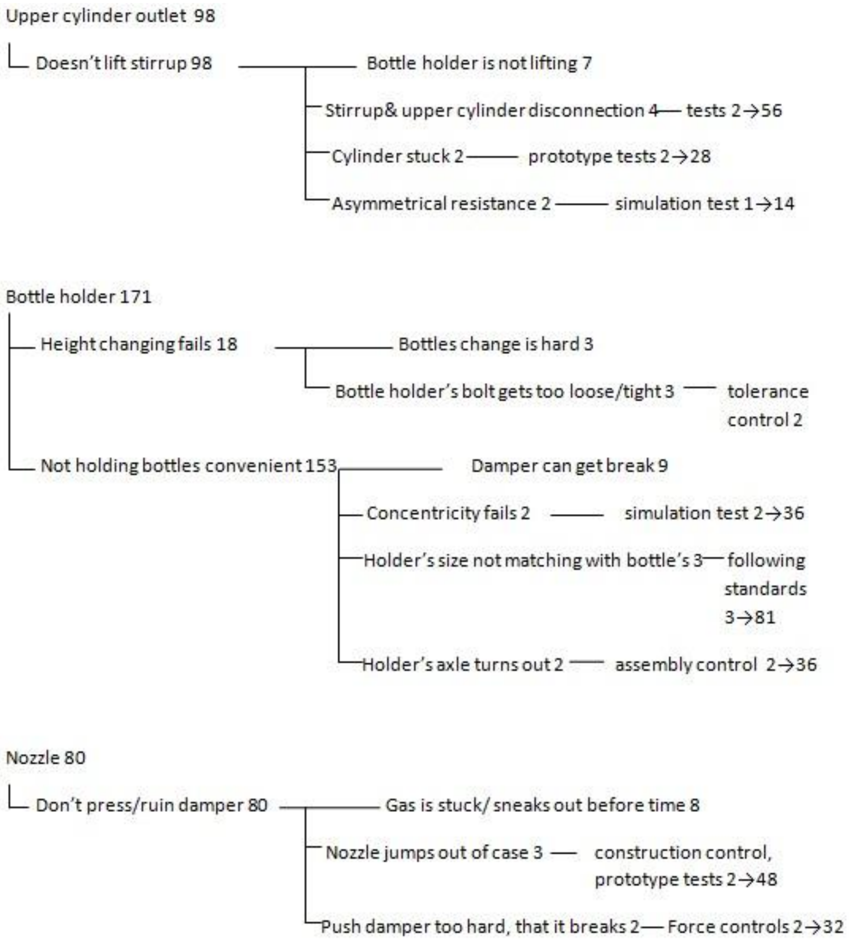


Figure 5: FMEA Analysis after changes

We can see, that the second FMEA's risk-priority numbers (RPN's) are not as high as were the first time. With our changes every risk priority number got less. We solved most of the problems, but the lower cylinder outlet (RPN=266) is still something on that we need to work. Probably after some prototype and simulation tests we can know more about that.

3. Simulation with computer models

When contemplating on design drawings we also try to take the aspects of robust design into account. We have to identify the outside and inside noises and find the way of how reducing their effect . The risk these noises bring about can be influenced by the changing proper design parameters [3]. The experimentation to get the correct value of these parameters should be made firsthand via computer-based simulation, in order to reduce the costs of making many variations of prototypes. Computer aided Motion Analysis can help us better understand the connections and relations between the parts and quantify motor torque and power consumption changes due to increased friction effects. Static studies reveal the unwanted deformations, stress and contact force concentrations that may impede right operation as a result of structural imperfections and/or noises.
The cases as follows were analysed:

- end of supporting screws loosely fitted in the bottle holder's boring;
- end of supporting screws loosely fitted in the bottle holder's boring;
- asymmetrical loading on both bottle tips.

RESULTS AND DISCUSSIONS

We started the calculation with steel material. When it's greased the amount of friction is µd=0.05 and µstatic=0.08. When it is dry the amount of friction is µd=0.25 and µstatic=0.3. From the result plots we can say, that greasing the helical faces, has a very strong decreasing effect. As shown in Figure 6, the needed power gets from 0.17 Watt to 0.07 Watt and the needed torque gets from 574 Nmm to 222 Nmm. Greasing the connection between the stirrup and the motor holder has just a smaller effect on these parameters.

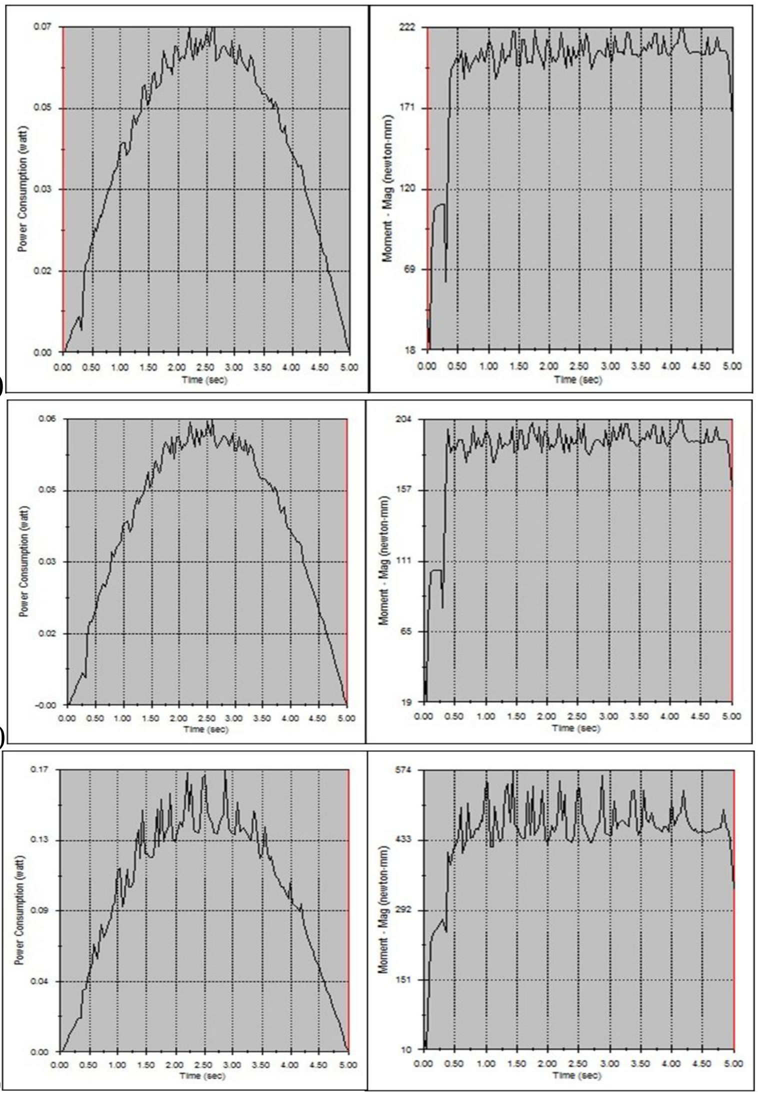
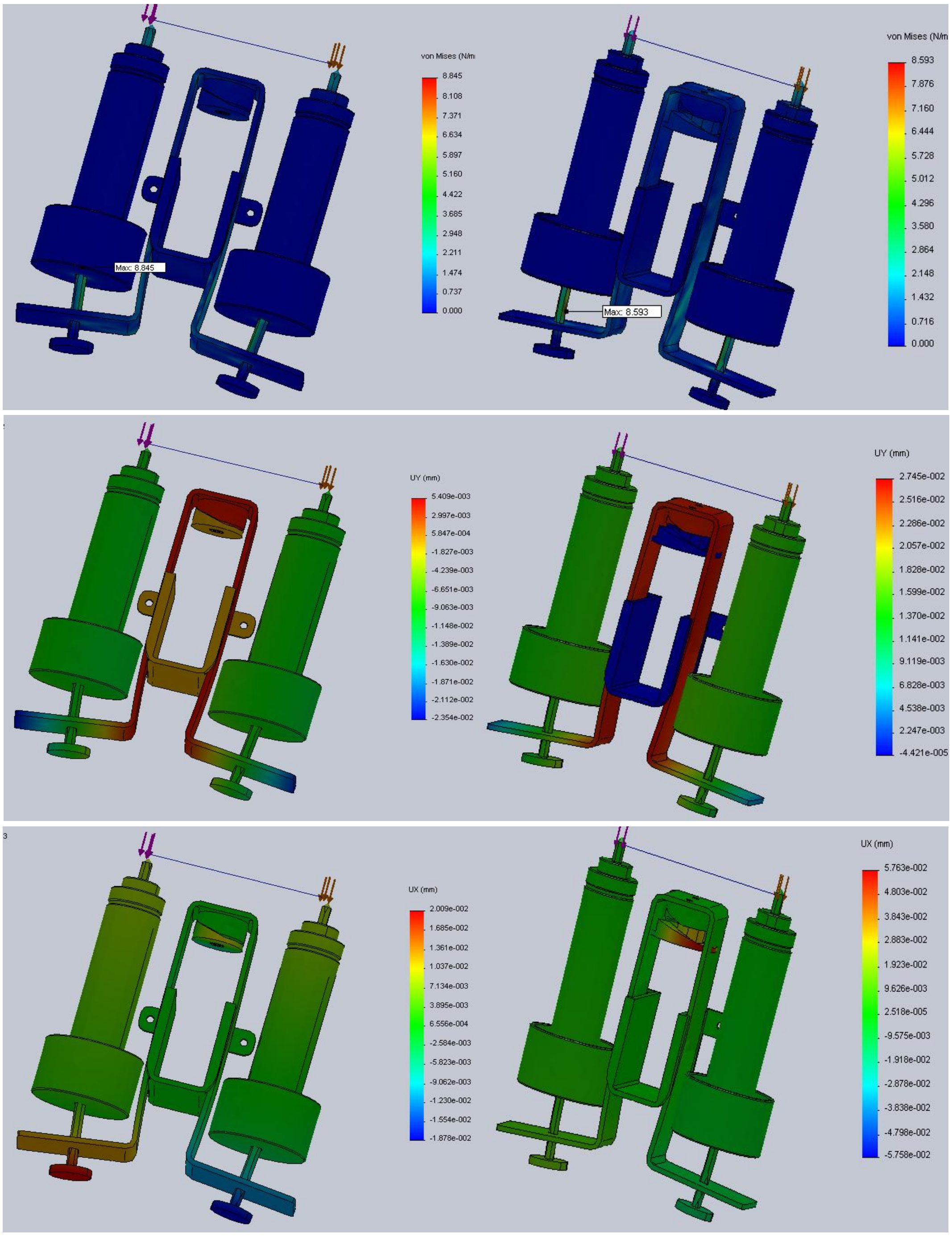


Figure 6: Motor torque and needed power with varying friction between the cylinder' helical faces and between stirrup and motor holder. a) cylinders greasy, b) cylinders and stirrup-motor holder connection greasy, c) all contacts dry

As regards static simulation, tightening the supporting screw in the bottle-holder's boring reduces the deflection of stirrup arms, thereby the difference between the planned and actual displacement of bottles, as clearly indicated in Figure 7. Stresses developed in the structural parts however are not much affected.



a)
b)
c)

Figure 7: Simulation results of the assembly with loose and tight supporting screw; on the left: supporting screws loose, on the right: supporting screws tight. a) Von Mises stresses; b) Vertical displacements; c) horizontal displacements

When comparing symmetrical and asymmetrical loading methods, we discover that displacement results are of similar magnitude, while stresses differ more. The deformed shape and the point of the maximum stress make us think. We might need a thicker and stronger stirrup and for the bottle holder's screw we could use a bigger diameter. Increasing screws' diameter the amount of the lifted weight is also getting a little more, but the screw could carry more with less deformation. Another option is to try to make the angle of the stirrups legs more fixed under load. That would require some little change of the stirrup's shape and dimensions that will still allow moving the bottle holders so much, that the product can be refilled. That solution could have a strong positive effect on the tolerance level between the stirrup and the motor holder. The amount of tolerance would be more stable. With these changes we might solve our problems, but it needs real prototype tests to control in the course of the further progress in the project.

CONCLUSIONS

Applying failure analysis methods of quality management as well as simulation on virtual computer models our team was able to detect and correct future failure possibilities. When using different approaches we always discovered something new, that we didn't think before. Our product is not perfect yet, but it is on a good way to get there. The development process is not complete yet, but it can be expected that through stepwise improvements the final design will perfectly serve its goals: starts operation with high probability in case of alarm and empties the flasks within a few seconds.

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