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PROJECT AND ANALYSIS OF A SMART DEVICE FOR DRUG DOSING

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Abstract: *We present results of our work on creating a new type of a device, purpose of which is to enhance drug adherence, and of research on data obtained by analysis of created device. Review of already existing examples was made, which allowed us to establish basic assumptions for creating the device. The best concept was modeled as a 3D CAD model, a Finite Element Analysis (FEA) was performed in order to check if the device is safe to use in terms of its ability of withstanding the weight of drugs put inside of the device as well as possible additional items which could be put in drugs-housing compartments, and finally a physical example of the device was manufactured.*

Keywords: **FEA, Drug adherence, Drug dosing, Pill organiser.**

1. Introduction

Increase of the amount of prescriptions (https://www.statista.com/statistics/238702/us-total-medical-prescriptions-issued/) combined with increasing problems with regular medication drugs intake are becoming more and more of an issue (DiMatteo et al., 2002 and Nagaraja et al., 2014), which is harmful both to the patient, and to economy (Nasseh et al., 2012). Doctors, companies and even governments search for solutions on how to increase both patients' awareness of necessity of regular drug intake, and probability of regular drugs intake. One of existing solutions are special devices purpose of which is to remind about necessity of regular medication intake. Such devices are usually called pill dispensers, pill boxes or pill organizers, and they serve the purpose of dividing medications into portions by times they are meant to be taken. It has been confirmed, that pill dispensers actually do have a positive influence on patients and help them take their medications regularly (DiMatteo et al., 2002), proving such devices to be a reasonable option for enhancing the medical drug adherence. Said devices come in wide variety of shapes, functions and designs, although after reviewing already existing examples some general trends can be pointed out – these devices usually have 3, 7 or natural product of 7 compartments for keeping the medication drugs, a single or combined alarm (e.g acoustic, optic, optic and vibrating etc.) informing about necessity of taking pills at adequate times, and they are usually round or orthogonal. Overall, functionalities of these devices are based on needs of intended user, it being either a patient her-/himself or a caretaker. Main problem of such devices is their price – cheap examples do not offer as many functions as more expensive ones, therefore people with greater needs have to pay more for devices that would be effective for them. Additionally, existing pill organizers are created in a way, that allows them

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to have only certain functionalities, and do not give possibility of customizing. Access to medication which is meant to be taken by patient at specified times is not always easy, since the pill-keeping compartments often cannot be taken out from the device, and the holes through which the pills are meant to be taken out are small.

Because of aforementioned problems a new concept of a pill dispensing device has been made. While creating an innovative device example we took into account the imperfections of already existing examples, and therefore intended to create a pill dispenser that would be affordable, easy to manufacture and have all functions that would enhance medication adherence.

2. Project and prototype of drug dispensing device

As part of our work a prototype of a new kind of drug dispensing device was created. Both electrical and mechanical components were selected, while other necessary parts were manufactured through use of a 3D printers, which allowed easy production of complex-shaped parts form desired material, and at a very low cost. Presented example is easily manufactured, selected components for its assembly are not difficult to access and it is designed in a manner that allows easy customization to fit needs of vide spectrum of patients with different needs. Compared to already existing devices, ours is easy to modify because of use of 3D printed parts and easily accessible electrical components. Along with all these traits our device is functional in its basic form, as it has 21 compartments in form of medication glasses, which can hold different amounts of medication pills, the compartments can be easily picked up from the device and patients and/or caregivers are informed about necessity of taking pills through a combined acoustic-optic alarm. The device is safe to use, as it has to be connected to a Smartphone or tablet by a Bluetooth standard in order to work, and this allowed us to make the device send reports and alerts to, for example, a caregiver or family member. In most cases, function of generating reports or sending alerts to other devices requires additional, periodic payment (https://www.medminder.com/). Our pill dispensing device has also been secured against unauthorized access to any (except for the one that holds medication meant to be taken at that time) of the compartments; tilting and shaking, which could cause the medication to mix up or fall out and become dangerous to use; and forcing the next dose of medication to become accessible. Such functions are available in only few of already existing examples (https://www.medacube.com/technology/).

Entire device was modeled as a 3D CAD object in Autodesk Inventor, thus allowing performance of FEA, estimating the durability of the device and checking its safety of use. Once the finite element analysis was performed and analyzed, a physical model was assembled (0). After assembling, electrical measurements were performed in order to check if all electrical components necessary for proper performance of entire device are working correctly.

Fig. 1: Assembled and working example of our device, with the 3D CAD model.

3. Input data for FEA of created device

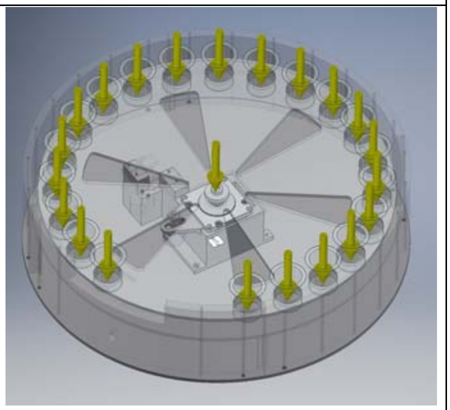
In order to verify durability of chosen conception for a new drug dispensing device a finite elements analysis was performed for two loading cases: one in which all 21 holes in the revolver plate were loaded by a medication glass and another, in which only 5 holes were loaded. Load of 1N was applied for bottoms of all used in analyzed cases medication glasses, earth's acceleration was applied for entire device, and it was held in place as immobile by binding the bottom plate of the device, as shown in 0.

Materials used for construction of the device were as listed below:

- ABS for all walls of the device and for the stepper motor housing,
- PMMA for the revolver plate, which holds all medication keeping glasses, and lower plate,
- Low density polyethylene (LDP) for the medication glasses,
- Construction steel (CS) for entirety of stepper motor, which rotates the revolver plate.

Properties of all above materials are listed in 0, all of which were taken from Autodesk Inventor 2018 material library.

Tab. 1: Properties of materials used in FEA and graphical representation of applied loads for 21 loaded glasses case.

	ABS	PMMA	LDP	CS	Graphical representation
Behaviour	Isotropic	Isotropic	Isotropic	Isotropic	
Young's module	2.240 GPa	2.740 GPa	0.124 GPa	210 GPa	
Poisson's coef.	0.38	0.35	0.41	0.3	
Yield strength	20 MPa	48.9 MPa	10.8 MPa	207.8 MPa	
Tensile strength	29.6 MPa	79.8 MPa	11 MPa	345 MPa	

Resulting values are presented in 0, and exemplary results are shown in 0. It is noticeable, that no value noted for any of the parts was greater than allowed maximum for the material the part was made of, and the safety coefficients were never smaller than 4.18, deeming our device to be safe to use.

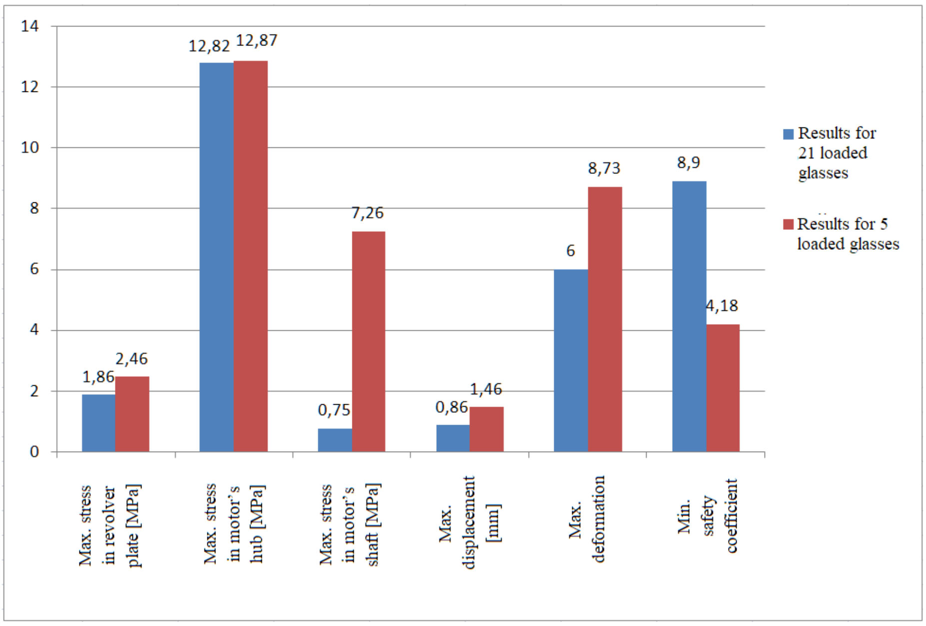
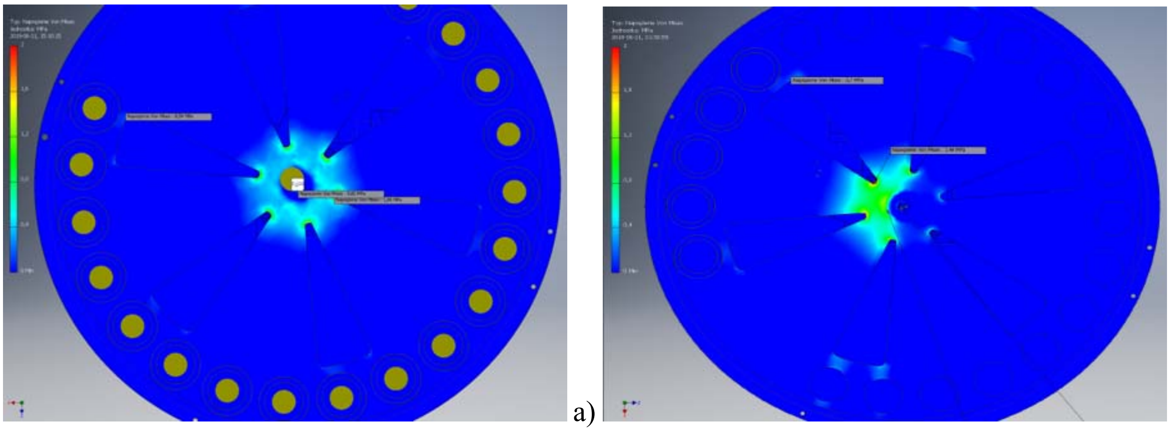


Fig. 2: The maximum and minimum resulting values received through FEA.

Performing the FEA as presented below allowed us to note that a more unfavorable case is the one with fewer loaded glasses. All measured values are greater (except for safety coefficient) in said case, than in the one with 21 loaded glasses, and differ in value from few hundredths, noted for motor's hub, to a few MPas, that occurred in motor's shaft. The load of 1 N was used as a safety measure, in case the device operator puts heavier, other than medication pills objects in the medication glasses, and yet the device was still capable of withstanding the overestimated load. Measured safety coefficients further confirm the safety of a pill dispenser – the lowest noted value in both cases was greater than 1.5, which is the lowest the device can achieve before it's considered unsafe to use, although again – its value for the case with only 5 loaded glasses is way smaller than for the 21 loaded glasses case.



a) b)

Fig. 3: Von Mises stresses obtained through FEA for a) 21 and b) 5 loaded glasses cases. Registered values are from left for a) 0.54 MPa, 0.82 MPa, 1.86 MPa, and for b) 0.7 MPa and 2.46 MPa.

4. Discussion

Presented pill dispenser was designed and manufactured as an answer to a specific market demand. Entirety of performed works was done on order of a caretaking facility, working both remotely and directly with people who are unable to live on their own. Through our work we managed to achieve the goal of lowering the price of end product while not giving up on any intended functionalities.

Produced device ensures safety, reminds about necessity of taking medication at appropriate times and is relatively easy to produce. Those traits have been achieved through use of appropriate electrical components, such as shake sensors, buzzers and LEDs, and because of use of 3D printing technique. Proper functioning of mechanical parts of the device has been verified through a FEA, and electronic elements were checked by doing measurements with an oscilloscope. All commenced tests allowed us to note that the device works as intended, although some upgrades could be introduced in next version of our device. For example, performed FEA allowed us to establish, that the revolver plate could be made even lighter by cutting out greater parts of it or by making it thinner. This would decrease stresses the stepper motor has to withstand, thus prolonging its lifespan and lowering the risk of it getting damaged. We also anticipate that manufacturing method of most parts will change - even though the 3D printing technique allows easy production of complex-shaped parts, it is too slow. For now, prototypes of the device are being tested in nursing homes with satisfying results.

Summing up, it seems that such devices have potential to become more and more popular among people of all ages since more and more medications are being used by people in general, and said devices would allow keeping up with necessary regularity of taking pills easily. Although, mass use of these devices is heavily dependent on the fact if their prices will keep dropping.

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