Design and Strength Analysis of the Base for Robot Baxter

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***Abstract*—** *This paper discusses the issue of the subsystem of mobility and solves the design of the lower mobile base for a robot called Baxter. In this paper you can see all the models and parts that are used in construction of mobile base, from which the initial model of the base is created. After making a model of a base, we were putting a load (represents the weight of a robot) on it so we could determine what kind of relative deformations and stresses are created by using finite element method analysis FEM. Later we optimised the base (for example we were changing the length dimensions of some parts), so we could get better results from FEM analysis and also, we wanted the optimised base to acquire similar dimensions and weight as a commercial base. At the end we created technical sheets of all the parts of the base. These technical sheets were later sent to university SIGMA in Clermont-Ferrand (France), from which they constructed mobile base for robot Baxter. FEM analysis was done in program called NX Siemens and models of individual parts were modelled in CATIA V5.*

***Keywords*— mobile base, subsystem of mobility, service robot, Baxter, strength analysis, finite element method.**

I. INTRODUCTION

Robots in today's world plays a very important part. General usage of robots is pretty much used everywhere. They are important in many departments such as engineering, medical, food industry or in various manufacturing processes where these robots are compulsory. Some of these robots have to move from one place to another and this can be provided by subsystem of mobility.

Baxter is a robot that resembles humanoid robot but it is service robot that was created and manufactured in company called Rethink robotics and as a start-up and founder of this company is Rodney Brooks. This robot is used for manual repetitive tasks for example storing, loading, retrieving and sorting which means that this robot can later in future replace human in these simple tasks. Baxter is used in many universities as a teaching aid in the classes of robotics, mechanical engineering and also in many IT departments. It is not required to use any safety requirements while using this robot in comparing with other robots. This robot simply stops when something interrupts its working environment. Only disadvantage of Baxter is that it does not have mobile base which means, it cannot move from one place to another.

The purpose of this article is to design subsystem of mobility for this robot. Company that created this robot is already selling commercial mobile base but it is very expensive where the price of this robot is around 40-thousand dollars. University in Clermont-Ferrand decided to create the mobile base for this robot which is going to be cheaper than commercial base and it is also going to have similar properties than commercial base.

First part of this paper is related to design of the mobile base where the first initial model is going to be loaded by the weight of the robot. Generated strain and deformation were calculated by using FEM analysis in NX Siemens. In the beginning of the FEM analysis we had to define materialistic properties to each model of the base. Later we compared these results with analytical results from selected beam of mobile base where we used method of differential equation of the deflection line to solve bending. In order to solve stresses, it was first necessary to determine the static conditions of equilibrium and determine course of bending moment.

Later, the base was changed, but in such a way that the weight and dimensions of the optimised based are approximately the same as the weight and dimensions of commercial mobile base. Weight of the commercial mobile base is around 80 kilograms.

At the end we simulated strength analysis of a wheel to determine relative strain and stress after one turnaround.

After optimising the base, we have chosen the final model of the mobile base. For this final model we created technical sheets that would be used for construction of the base.

II. DESIGN OF THE MOBILE BASE

The whole design of mobile base is simplified, as the robot will move and control on a flat surface and movement of the robot on inclined plane will not be considered. Design does not consider the use of ordinary wheels but the unidirectional wheels (Omni wheels) which compared to ordinary wheels, do not require turning the front wheels or by using auxiliary wheels in order for a robot to turn. These wheels provide the advantage that robot can easily rotate around its own axis.

Another simplification of the design of the mobile base is the fact that the robot stands straight and does not bend, therefore we do not consider the movement of the robot on an inclined plane. The locomotive system of the mobile base for Baxter robot consists of two shafts which are connected by a clutch, one shaft is connected to the motor and the other is connected to the wheel. Information on shafts regarding the dimensions and motors for the mobile base, which were calculated and selected by students at SIGMA University in Clermont-Ferrand (France), was also used for design of the mobile base.

The mobile base consists of two main parts, which are the upper part and lower part of mobile base.

The upper part is used to carry the robot and forms driven axle. In this part it was necessary to create a platform, on which robot will sit. The lower part forms drive axle. At the end we created a support element that connects these two parts together.

The optimised model (Fig.1) of driven axle of a mobile base consists of these parts:

TABLE 1
USED COMPONENTS FOR CONSTRUCTION OF MOBILE BASE

Component	Dimensions (mm)	Quantity
Platform	378x360	1
Aluminium profile	90x90x800	4
Aluminium profile	93x45x680	2
Aluminium profile	93x45x450	4
Aluminium profile	93x45x139	2
Aluminium profile	93x45x216	2
Connector	87x87	8
Connector	35x35	14
Bolt screw	M8	32
Nut	M8	32
Bolt screw	M6	44
Nut	M6	44

The drive axle of the movable base consists of the following main components: protective box, motor, platform (on which the motor is mounted), two shafts, clutch, bearing, wedge, OMNI wheel (unidirectional wheel), connectors (connecting the drive axle to the driven). For the drive axle, it is necessary to distinguish between the left and right side, which differ from each other by the wheel.

Locomotion system of the base consists of two shafts, bearing, clutch, engine and wheel. One of the shafts is connected to the wheel and the other is connected to the engine. As a bearing we used flexible coupling RGS-AL24 with rubber rollers, which connects shafts together. Because of the dimensions of shafts, a double-row ball bearing with angular contact by norm STN 02 4665 was determined. The type of bearing we used A-2Z/C3. As an engine we selected Dynamixel PRO L42-10-S300-R. This type of engine is commonly used as an actuator in many robots. As a wheel we used Mecanum wheel or unidirectional. On this wheel there are external rollers. Each of the rollers has an axis rotation of 45° to the plane of the wheel and 45°to the axis of the axle. The main advantage of these wheels is that robot does not need to turn front wheels in order to change the direction of the robot. Robot can simply rotate on its own axis to change the direction.

Later we optimized the base by changing length dimensions of individual parts of the base with intention that our base must resemble the size and weight of a commercial base.

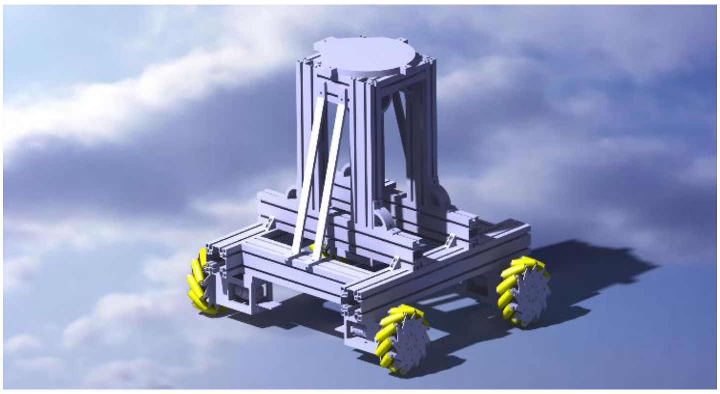

FIGURE 1: Optimized mobile base of a robot Baxter

III. STRENGTH ANALYSIS OF THE BASE

In the first step, it was necessary to convert the model created in the Catia V5 into the NX Siemens, in which strength calculations were performed using finite element method FEM. The total strength analysis can be divided into two parts, where in first part we calculated strength output parameters for the whole structure except for wheel. In the second part we performed strength analysis on the wheel by using quarter model.

3.1 Determination of materials for individual parts

TABLE 2
MECHANICAL PROPERTIES OF USED MATERIALS WHERE Re- YIELD STRENGTH, Rm- TENSILE STRENGTH, μ- POISSON RATIO, ρ- DENSITY, E- YOUNG MODULUS

Material	Re (MPa)	Rm (MPa)	μ	ρ ($\frac{g}{m^3}$)	E (MPa)
Steel 12060	420	750-900	0,3	7,86	$2*10^5$
Aluminium steel 6061	276	310	0,33	2,7	$6,89*10^4$
Nylon 66	60	85	0,35	1,2	3500

3.2 Determination of boundary conditions

In the first part of strength analysis, it was necessary to determine the connections of the individual parts before the start of the simulation, so the first boundary condition is surface to surface connection. As the second boundary condition we had to define fixed support. The fixed support was defined on the plate of each wheel by which we calculated deformations and stresses on each part of the mobile base except for wheels. Before we could start the simulation, we had to put a loading force generated by weight of the robot on top of the platform of the mobile base. The force is perpendicular to the plane of the platform with around 800N.

TABLE 3
CONDITION SEQUENCES WHERE Fx IS FORCE IN x DIRECTION AND Fz IN z DIRECTION

Condition	Parameters [N]
0-1: 0°	F_x= 400; F_z= 0,1
1-2: 45°	F_x= 283; F_z= 283
2-3: 90°	F_x= 0.1; F_z= 400
3-4: 135°	F_x= -283; F_z= 283
4-5: 180°	F_x= -400; F_z= 0,1
5-6: 225°	F_x= -283; F_z= -283
6-7: 270°	F_x=0,1; F_z=-400
7-8: 315°	F_x=283; F_z=-283

In the second part of the strength analysis, we had to determine deformations and stresses generated on the wheel after one turn. In this part of analysis, we had this boundary conditions: creating condition sequences so we could determine strength parameters after 45° rotation of the wheel (Tab.3.) with around 400N (force generated by quarter of the weight of whole structure of the robot); fixed support that was created on the created plane located on the plate of the wheel; surface to surface connection to connect all the parts of the wheel together.

IV. RESULT

The highest elemental stresses arose on the shaft, where the maximum values where around 3.5 MPa. The nodal stress reached around 5 MPa after averaging the result. The maximum deformation values were around 0.01 mm (Fig.3).

The resulting deformation on the wheel was minimal with maximum value of 0.006 mm and stresses, which according to calculation reached the value of 44 MPa. Based on origin and spreading of stress, we can state that bending was occurring, which means that calculation was successful (Fig.4).

Later we did analytical calculation of stress and deformation on a beam of aluminium profile of the base to determine, if the simulation was done correctly. We chose beam of aluminium profile with dimensions 93x47x680. The calculation was simplified and we considered simple rectangular cross-section with dimensions of 93x47. Two equally large forces of 250N were put on a beam (Fig.5.) and „a" represents third of a length of a beam. Initially it was necessary to solve reactions from static equilibrium conditions and to determine the course of moments and forces of this beam. Resulting stress of the analytical calculation was 1.5 MPa and maximum deformation was around 0.08mm. Values of deformations and stresses calculated by analytical calculations where very similar which means the simulation was done correctly.

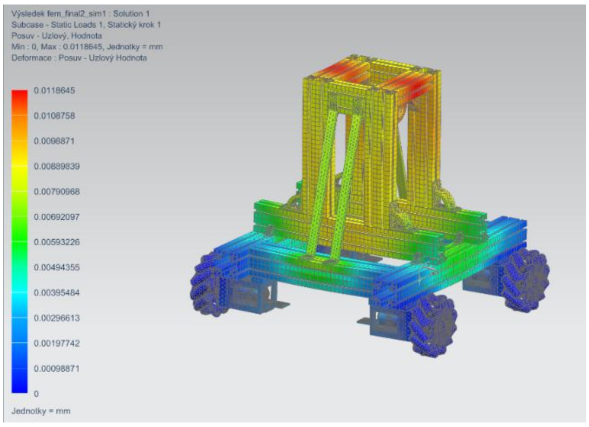

FIGURE 3: Deformations of the base

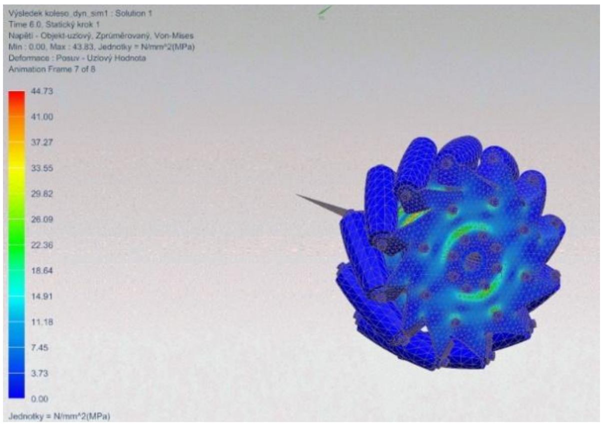

FIGURE 4: Stresses on the wheel

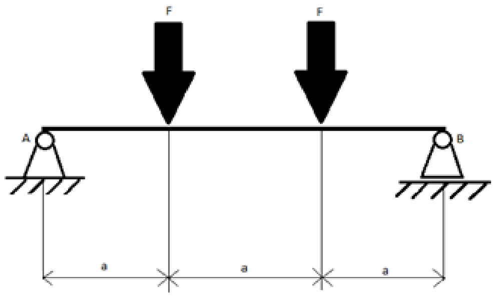

FIGURE 5: The selected beam of the mobile base used for analytical calculation

V. DISCUSSION

Based on the obtained results, we can state that in terms of strength, the base corresponds to the loading conditions that were generated by weight of the robot which is approximately 80 kilograms. The yield strength of each material used in the base is significantly higher than the stresses that were generated on the whole structure of the base. Later we created technical drawings for the construction of the individual parts, which were sent to the University in SIGMA in Clermont-Ferrand by which they will build the base.

VI. CONCLUSION

The main task of this work was to create a mobile base for a robot Baxter. At the beginning, there was created a first model of a base which was later modified so that the size and a weight was similar to the commercial base. It was also a priority to save money by creating this mobile base for a robot, as a price of a commercial base for a robot is approximately $40,000 and more. The total cost of this base was around 5,000 €, which saved us a lot of money. This work can of course be continued. Its continuation would be programming the whole system into motion, where for example joystick would be used to control the base itself. Since the base uses simple parts of the drive axle and the question of turning is solved by unidirectional wheel, the mobility can be improved by turning the front wheels as in automobiles.

ACKNOWLEDGEMENTS

This paper was written with the financial support of the granting agency VEGA within the project solution No. 1/0108/19 and No. 1/0626/20 and of the granting agency KEGA within the project solution No. 005TUKE-4/2019.

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