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DESIGNING PNEUMATIC CIRCUIT OF A CHEESE SLICER

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Abstract: The design of the cheese cutter system was the one of the project topics in the HEIBUS project in 2017. My task was the design of the pneumatic system, which is used by the machine. I made the easiest solving, which complete the demands, which the design stands up. After then I sizing the main part of the circuit, and choose the other parts. I make some test in final elements program.
Keywords: *cheese cutter, pneumatic system, design, sizing*

1. INTRODUCTION

In 2017, the HEIBus organized two; international project works in Europe between three country's universities. One of these projects is a design of a cheese cuter machine and this project attended a Romanian, a German and a Hungarian university, the University of Miskolc. We got this task from the AutoMates Company, which products special machines for the industry, in this case for the food industry. A student team has six members, two students from all three universities. From the three team two took apart an intensive week in Cluj-Napoca, and one of team follow the presentations of the intensive week online. On this week the students and the mentor professors visited presentation about the Company, the task and the technical solutions which will be useful for the project.

As I wrote, the task was given by the AutoMates Company, and this company given some points, which we had to take into the account in the designing process. This point is connecting to the demands of the food industry, especially the dairy industry. In their presentation showed the demands and the suggestions.

Some points from the demands:

- full pneumatic system
- easy cleanable parts
- non-electric part
- easy transportable construction
- use Festo's pneumatic parts

In the dairy industry the speed and well organized production process are very important because of the easy perishability [1]. One of the main demands is the full pneumatic system. In food industry the pneumatic system is the best driving solution, because it clean, the “fuel” is not pollutes the environment and the productions. The working elements have simply structure, and because of it this parts are relatively cheaper, than another method.

The pneumatic system has some bad point. For example, the air needs preparations. The “fuel” does not contain contaminations or water, because these cause the shorter lifetime of the circuit parts. This preparation and air compression for the right working pressure value is expensive. The air is squeezable, so we cannot use for precise positioning [2].

Another point is the easy cleanable and stainless parts. It’s important, mainly in the dairy products. So, we have to design the parts from plastic, stainless steel and another material, which are compatible with the food industry [3].

The wet and damp environment requires the non-electronic parts in the pneumatic system. The construction have to be simple, and easy packable, because the machine manufacture want easy transportation between the manufacture and the food industry. The main part of the designing was the collecting the ideas for the problem solving. The project stands the main demands, and we made the ideas. We, the team discuss idea and we selected the best one, which solve the problem and optimize the system, and costs. It was not easy, because often the best one was the most expensive.

2. THE PNEUMATIC CIRCUIT

The *Figure 1* shows the basic pneumatic circuit of the machine.

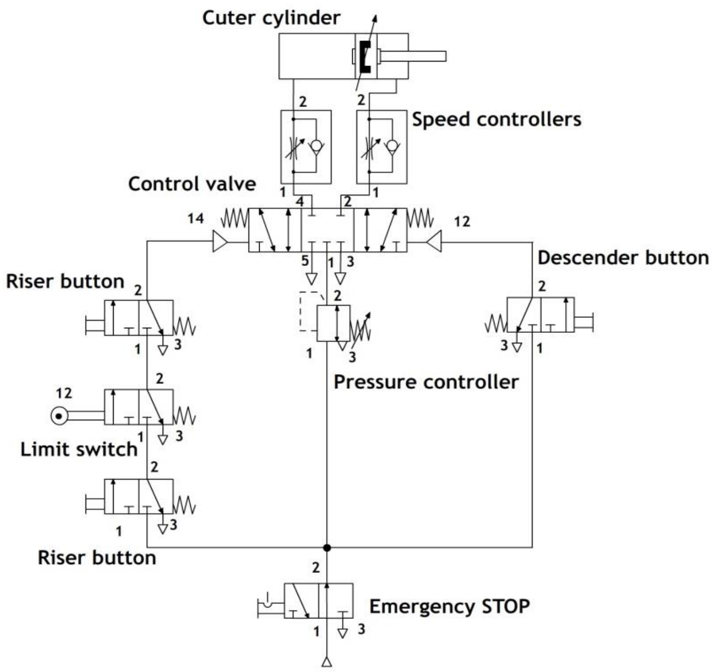

Figure 1. The pneumatic circuit in progress

One cylinder and these cylinders push up the cheese, which is on the plate, thought the blades' frame. The plate has trenches, for the blades to the full cutting, like the French fries maker. We choose this plan, because, in our opinion, this is the less expensive system. The size of the machine is significantly decreases with this circuit. The cylinder is stands vertical, and the height of the cheese is smaller, than the other parameter, so we do not need long stroke length. This layout causes, the gravity helps to keep the position of the cheese on the plate. The sketch is in the *Figure 2*. This sketch includes the main construction, and the main movements.

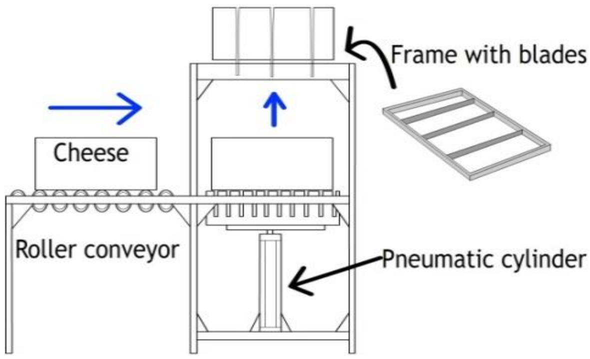

Figure 2. The best idea's sketch

2.1. Working

The preparation unit is not on the plan, but in the design process, I choose it, and it includes the main parts of a preparation unit, like the filter, the humid condenser, oiler and manometer.

The *cutter cylinder* goes out to the outer limit position, if the operator pushes simultaneously the two *riser buttons* and the *limit switch*. The limit switch is built in the door of the cutter chamber. If the switch is active, this indicates the door is closed.

If the worker opens the door, the controlling valve goes back to central position and the cylinder is stops. This action is activate the 5/3 *control valve*, and the working pressure can flow through it, and push the cylinder out. The *riser buttons* are connected each other in *AND* logic, so the mechanism is working just we push the buttons. The *riser buttons* are 3/2-es directional, mono stable valve, with spring returning.

The 5/3 directional valve central state is closed state, so when both sides are active, the valve is closed, and the cylinder holds the position. We can use this function to positioning between the two limit positions, but it is not accurate, because the air is squeezable.

After the 5/3 valve, – in the pneumatic line – is *the speed controllers*. With this one way flow control valve the worker can sets the speed of the cylinder movement. This valve sets just the outgoing speed.

Then the cutting is over, the worker can set the cylinder in the starter position, after he or she take off the cut parts of the cheese, if he or she pushes the *descender* *button*. This valve activates the 5/3 valve for the other ending position. This causes the reverse movement of the cylinder. The *descender button* is a 3/2-es directional, mono stable valve, with spring returning.

For the safety function, the circuit contains an *Emergency STOP* button. This is a 3/2-es directional, bistabile valve, whit spring returning. If the Emergency STOP button is pushed, the valve is cuts the source air pressure from the circuit and the 5/3 valve stands into the center position.

The engineer can sets the air pressure with the *pressure controller valve*. This valve controller is a rotary button on the interface. The engineer can adjust the pressure between wide limits.

3. INTERFACE

Every valve, which is in contact with the operator, is going out to the interface. The other point in the safe working list, the emergency stop button is in the interface too. The pressure and speed controller dials are got a place on the interface. The manual of the machine must be on clearly visible place on the interface [1].

4. SIZING

4.1. Choosing of the cylinder

The cylinder is the actuator part of the machine, because this tool transforms the moving (in our case the cuter moving). In the choosing and sizing process the acting forces are the start points both of them the regulation of the food industry.

The sizing processes have been started with the cylinder type choosing. The FESTO has cylinders from stainless steel, which material is used in the food industry. The stroke length is depend on the size of the cheese which is known from the requirements list. The height of the cheese is 150 mm (C), we need some place for the positioning (P) is 100 mm and, for the full height cutting we need the thickness of the blades' frame (I) which is 25 mm. These distances are showed by the Figure 3.

$$S = C + P + I \tag{1}$$

The S stroke length is 275 mm, from the (1) equation. After then, the piston diameter has been determined. For the diameter, we have to know the cutting forces, which can calculate from the (2) equation:

$$F_C = F_{CcA} + F_{mc} + F_{mp} \tag{2}$$

Where:
F_{CcA}: The force for the blades cut the cheese totally [N]
F_{mc}: The mass of the cheese [N]
F_{mp}: The mass of the cutting platform [N]

We use the results from the cheese cutting experience, which made by another team member. He said the F_{Cc} force on one blade is 1700 N.

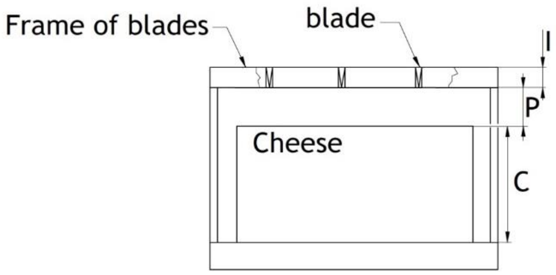

Figure 3. The cutting chamber with the cheese

For 3 blades (because the machine cut the cheese for 4 parts), as we do in (3) equation:

$$F_{CcA} = 3 \cdot F_{Cc} \tag{3}$$

From the (3) formula the F_{CcA} force is 5100 N on the three blades. The next force, which the piston has to explicates, the mass of the cheese, because the piston raises it. For the calculation we get the pack of the *Gouda* cheese. A general pack of the *Gouda* is a block with 300 mm diameter (r), 75 mm thickness (h) and 4 kg mass (m). From the (4) formula we get the volume V:

$$V = r^2 \cdot \pi \cdot h \tag{4}$$

We can count the density of the *Gouda* ρ from the (5).

$$\rho = \frac{m}{V} \tag{5}$$

From this point, we easily get the mass (m) of the block of cheese with the (6) formula, which we use in this project:

$$m = V \cdot \rho \tag{6}$$

Where:
V: the volume of the block [which is calculated from the (7) equation]:

$$V = a \cdot b \cdot c \tag{7}$$

Same way we can count the mass (m) of the *Kaskaval* cheese block, which is as type as the *Gouda*'s block, from the (6), and we know the density of the *Kaskaval* is 230 kg/m^3.

We continue the task with the mass of the *Gouda*; we make this decision, because this cheese is harder, than the Kaskaval. The force F_{mc}, from the (8) formula.

$$F_{mc} = m \cdot g \tag{8}$$

The mass of the cutting platform is depending from the design and the material. From my team members, we know the mass is 14 kg. After then we multiply with the gravity coefficient (9) formula, and the F_{mp} is 137.34 N.

$$F_{mp} = 14 \cdot g \tag{9}$$

Where the g is the gravitation coefficient and, this is 9.81 m/s^2.

From the (2) equation, we get the cutting force F_C,

I calculated some plus force the safety, this plus is 10% of the F_C, and we need this, because we have not got cutting force dates from the Kaskaval cheese, consequently the F_C force is 5900N.

The results are included the *Table 1*.

Table 1.
The results of the calculations

Number of equation	**Data**	**Result**	**Dimension**
3	F_{CcA}	5100	N
4	V	$5.3014*10^{-3}$	m^3
5	ρ	752.72	kg/m^3
6	m	6.9	kg
7	V	0.03	m^3
8	F_{mc}	221.5255	N
9	F_{mp}	137.34	N
10	F_C	5458.8655	N

We can open the catalog from FESTO’s stainless steel cylinders, and I found the *Table 2*:

Table 2.
The main properties of the cylinders [2]

Force [N]							
Piston ø	32	40	50	63	80	100	125
Theoretical force 6 bar, advancing	482	753	1178	1870	3015	4712	7360
Theoretical force 6 bar, retracting	415	633	990	1682	2720	4418	6880

As you can see on the *Table 1* the piston wit 125 mm diameter will fulfill the requirements. The chosen cylinder is: RDNG 125 275 PPV. In this type code the RDNG means the type of the cylinder. The number of 125 is the diameter of the piston rod and the 275 is assigning the length of the rod. The PPV abridgment says the type of the attenuation of the piston head, and this exactly pneumatic cushioning, self-adjusting at both ends. This cylinder type is showed by the *Figure 4*.

Figure 4. The chosen cylinder type [2]

After that I checked the piston rod for buckling. For the good working of the piston, this calculation is important. At firth, I determined the end-condition of the piston rod, which is the fixed-fixed type; because both end of the rod are do not include joint-pins. We can understand this choosing from the *Figure 5*.

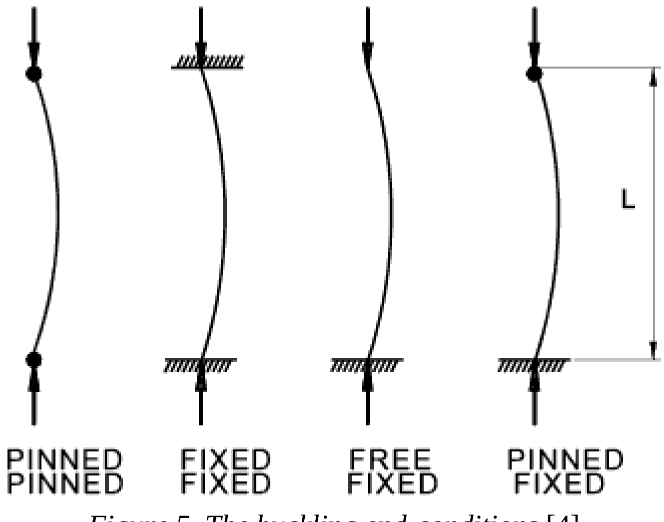

Figure 5. The buckling end-conditions [4]

This end-condition type releases the effective length (l_{eff}) from the (10) formula:

$$l_{eff} = 0.5 \cdot L \tag{10}$$

Our piston rod's length is 275 mm from the (1) equation, from that data the effective length is 137.5 mm. This data is required for the slenderness ratio calculation, which is showed by the (11) formula:

$$\lambda = \frac{l_{eff}}{k} \tag{11}$$

Where:
λ: Slenderness ratio
l_{eff}: Effective length [mm]
k: Radius of gyration [mm]
The radius of the gyration is calculated from the (12) equation:

$$k = \frac{d}{4} \tag{12}$$

Where:
d: diameter of the piston rod

In this case the *d* is 32 mm, so the *k* factor is 8 mm. If we have the l_{eff} and the *k*, we can get the slenderness ratio, which is in this task 17.188. In the next step I saw the graph, which show the critical values of the slenderness ratio, and the buckling method of that values, in the *Figure 6*.

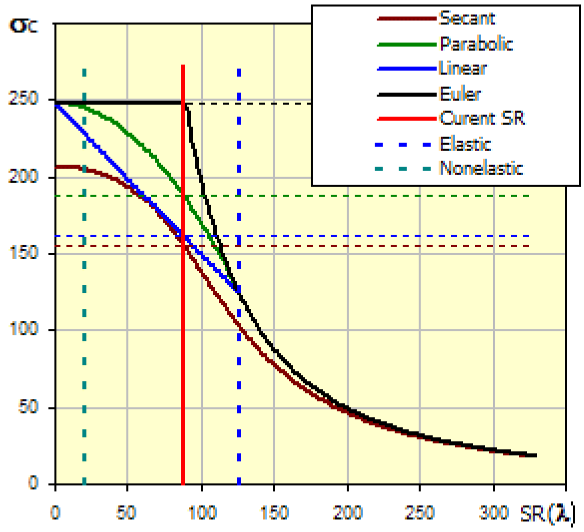

Figure 6. The context between the slenderness ratio and the buckling method [5]

Slenderness ratio in this task is 17.188, which is under the slenderness ratio of the red line in the *Figure 6*, it follows that, the rod is right, because the failure is not caused by the buckling in the working process, and we do not need more calculation [6].

4.2. Choosing of the valves

The main standpoint in the valve choosing progress is the flow. Besides that it was important is the operating. The 5/3 valve is pneumatic operated, the other valve is hand operated, with spring return. Pressure controller valve: LRMA-1/4-QS-6. In the choosing of the valves is a main point the connection types, it is important if we want to connect the valves in one circuit.

- 3/2 directional valve: VHEM-PTC-M32C-M-G18
- 5/3 directional valve: VL-5/3G-1/8-B1
- Emergency STOP: KH/O-3-PK-3
- Speed controller valve: GPR-160-1/8-AL
- Air preparer unit: MSE6-E2M-5000-FB37-AGD

In the pneumatic lab of the University of Miskolc I can build the circuit for testing.

5. Finite elements modelling

Basic of my calculations, the piston rod get almost 5900 N presser force, and I was curious, this force how much deformation causes on the rod. I analyzed the rod, because in my opinion this part of the system gets the biggest load.

A simplified model of the rod has been made in Solid Edge software, and the analysis has been made in Ansys. With this program, we can simulate a lot of loads from the engineering practice. As we can see on the under figure, I create a mesh on the model of the rod in the *Figure 7* shows.

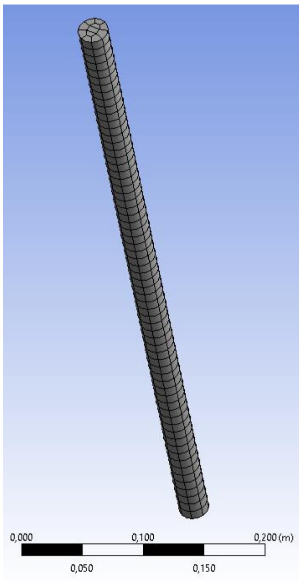

Figure 7. The rod after meshing

Secondary, the surfaces is marked, where the support is, and where the force's attack point is. After then, the force's value and direction are set, and the simulation is begun. The total deformation and equivalent stress are analyzed. Some surface in the rod is cut, because I want to see the stress' parameters inside the body of the rod.

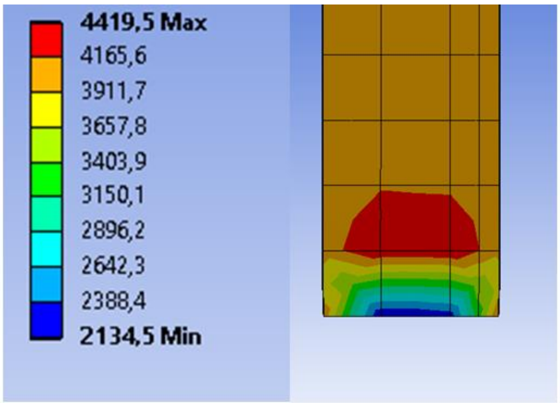

Figure 8. The stress in the rod, the support's side, and the scale in Pa

The left side of the *Figure 8*, the test bench has a scale, where the minimum and maximum values are readable of the stress and deformation. In my simulation the maximum stress is inside the rod and this value is: 4419.5 Pa. The maximum deformation is $1.3613 \cdot 10^{-8}$ m.

After then, I look for the *Table 3*, which contains the limit values of the stainless steel stress. The lowest non-proportional extension with 125 mm diameter is the 180 MPa, and the alloy is the X 3 CrNi 19 11 [7].

3. Table

The X 3 CrNi 19 11 stainless steel alloy parameters [8]

Mechanical properties at room temperature			
Size	$R_{p\,0.2}$ [MPa]	$R_{p0.1}$ [MPa]	R_m [MPA]
d ≤ 160 mm	180	215	460–680
160 < d ≤ 250 mm			
s ≤ 100 mm			

The diameter meets the requirements.

After that I made a test for buckling, that important because the high value of the buckling is disturbing the working of the piston. I stayed with the Ansys program, and I did the beginner steps like the previous analyzation. The support and the effective interface the same, just like the force, but now I am solving with the buckling. The test's result is showed by the *Figure 9*. The red color signs the biggest buckling in the time period of the force working. At the support surface the buckling is zero, and this area is signed with blue color. The simulation visualization is overacting for the easier understanding.

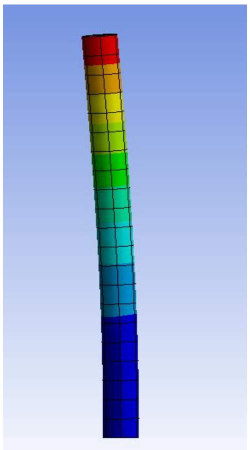

Figure 9. The buckling test's result

Important information from the test is the value of the load multiplier. In this case this value is almost 27.2, and this means, we can use the working force 27.2 times and the rod is buckling enough for the dysfunction. From above that value the rod buckling to lot for the normal working, and this test confirms the calculations in the chapter 5.

This test confirms to the statement, which says: the parameters of the rod meets the requirement.

6. Possibilities of developments

If I want to connect this system to a production line, it has to contain some plus cylinders and movements, which triggers the in loads or out loads the cheese. With a cascade circuit we can do that. With two cylinders, the system is solving the cheese cutting and the cheese transportation. This process can be automated. However the two cylinders increase the costs of the system, and the machine, because the system needs more valves and more tubes. The cylinders flow chart is presented by the Figure 10.

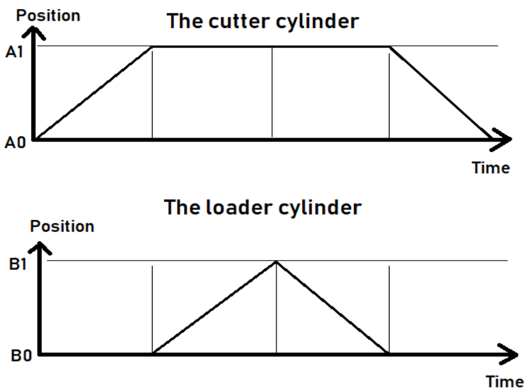

Figure 10. Flow chart

The loader cylinder can pushes the cheese on the cutter surface, or pushes out the pieces of the cut cheeses, above the blade to a conveyor belt.

7. CONCLUSIONS

In the *Figure 11* shows the 3D model of the machine, which we designed. We did not use of the roller conveyor, because the load process is solving manually. I think this construction meets all expectations.

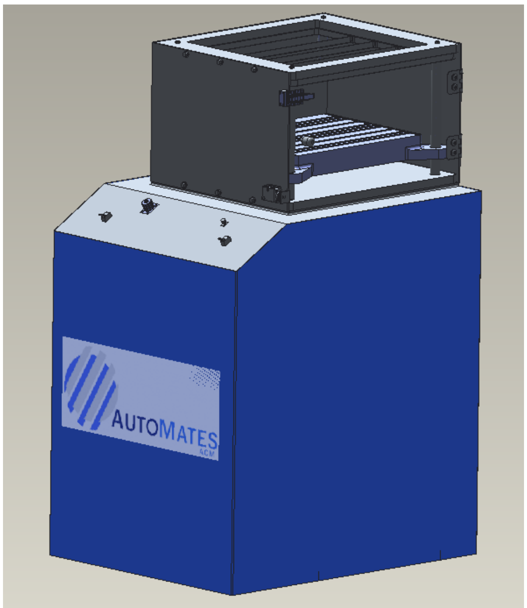

Figure 11. The Model of the cheese cuter machine

This project was very useful, one part, we can develop our professional language, and we were able to practiced it, and the international teamwork. We met other culture thinking mode and problem solving. The weekly team meeting gives possibility to the discussion of the ideas and talk about the task and problems. And we can see I use the result of experiments, which was made by another team member, this need high reliability.

The topic of the project was good, because it was a real-life problem, with the engineer can meet easy in the career. I enjoyed it, because the upper points and it gives me some, if not so much, experience about the system designing, and team working.

I would like to thanks for the professors, who help us while we solving the problem, and help for me to write this article. Without this help, we did not study so many useful things about the real life problem solving.

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