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OPTIMIZATION OF THE MILKING MACHINE CLAW SHAPE WITH THE USE OF THE FLOW SIMULATION SOFTWARE[1]

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ABSTRACT

The objective of the research was to optimize the shape of the milk chamber of a claw using Computational Fluid Dynamics (CFD) software. The results of the liquid flows simulation in claw models of various shapes, in particular with different aspect ratios defined as height to diameter ratios were presented. The velocity of fluid and interactions between different streams of liquid flowing out of inlets were analysed. The research was carried out at the flow of liquid from 0 to 10 kg·s^{-1}, vacuum of 38 to 50 kPa, simulating air injection into the claw model. It was found that the best conditions are for models with an aspect ratio of approximately 3. Computed liquid flow rates ranged from 0.05 to 1.2 m·s^{-1}.

Introduction

Since the last decade of the previous century, a dynamic development of production informatization has taken place, which is possible due to more technically advanced computer systems and also due to timprovement of software and constant decrease of computer equipment prices. IT techniques are applied in many stages of production processes also at designing for agriculture (Szczepaniak, 2010). Designing of devices and their elements more often takes place only directly in a computer, without creating physical prototypes. To begin with simple objects of everyday use through car bodies and to end with elements of a power station, computer designing creates many advantages. These advantages include decrease of costs, optimization of work time of a designer and possibility of testing numerous variants of a design. Moreover, visualization of the final product is possible. It is helpful, inter alia, in a situation, when the designed element is a part, which may cooperate with elements constructed by other designers. As a result an optimal version, designed for making the final prototype or almost directly for production, may be obtained. There are numerous systems which comprise the Computer Integrated Manufacturing. One of them is CAD system - Computer Aided Design and CFD system –

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Computer Fluid Dynamics. Due to the mentioned systems, elements or systems of elements may be designed and liquid and gas flow inside or around those elements may be analysed.

There are many programmes both commercial (e.g. Fluent ANYSYS, FIDAP, STAR CD, Abaqus, SolidWorks Flow Simulation) as well as OpenSource (e.g. OpenFOAM, Free CFD, OpenFlower), thanks to which liquid and gas flow may simulated in real conditions.

In the structure of milking machines, including claws, more advanced solutions are applied, such as e.g. quarter milking, intelligent milking machines, which allow limitation of overmilking from particular quarters (Jędruś and Lipiński, 2007; Jędruś 2011) or solutions which automatize the milking process on account of smooth adjustment of negative pressure to the changing milking conditions (Juszka and Tomasik, 2005; Juszka et al.., 2008). However, costs and low complexity of traditional milking machines and claws with one milk part of a chamber common for milk obtained from all teats cause that such solutions are and probably will be applied for a long time. Thus, optimization of each element of the milking machine on account of reaching efficient milking without disturbances, the least harmful for an animal is important (Pazzona et al., 2010; Krzyś et al., 2010; Sharif and Muhammad, 2008; Sitkowska, 2008).

Objective and scope of the study

The objective of the study was to design milking machines claws with a possibly optimal shape and volume and optimization of the claw shape with the use of a fluid and gas flow simulation software, including current research results.

The studies covered few hundred models of collectors designed in CAD system. Simulations were carried out with the use of CFD software.

Methodology of research

The starting point for construction of claw models were tests carried out including the existing 13 variants of available claws, their geometric parameters, shaping pressure parameters of mechanical milking with the use of those claws and determined impact of a claw on pressure conditions inside it (Krzyś et al., 2013). Moreover, researches consisting in the measurement of milking parameters with claws of various shape factors, that is, ratios of diameters of the milk part to their height, constituted the basis (a schematic representation and pictures of exemplary models from this part of research were presented in figure 1, whereas parameters in table 1). The research results allowed stating that the most advantageous pressure conditions exist in claws with the highest and the lowest values of the aspect ratio. Due to practical reasons, models with the lowest aspect ratio were not taken into consideration (models with high milk chamber) because they are functional during milking in a cowshed - a milking machine cannot hang freely from teats, it leans against the floor. Thus, the starting point for the research was the claw model with the aspect ratio amounting to 3 (after including the research results of the existing claw solutions (Krzyś et al., 2013) and research results on machines with claws presented in fig. 1).

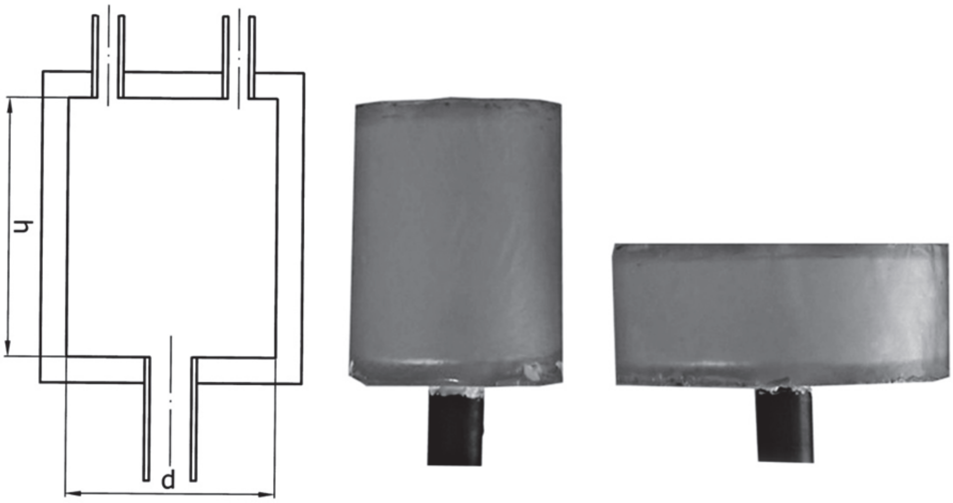

Figure 1. Schematic representation of claw and exemplary epoxide resin models used in the initial tests

Table 1
Dimensions of milk claw parts made for initial tests

Claw	1	2	3	4	5	6
Diameter of milk part, (mm)	70	80	90	100	120	130
Diameter of milk part, (mm)	130	100	79	64	44	38
Aspect ratio, (-)	0.54	0.8	1.39	1.56	2.73	3.42

Claws, the structure of which was developed in the modelling software of CAD type were the objects of investigation. With the use of the fluid flow simulation software, behaviour of the liquid flowing through claws was analysed. The obtained results were used for initial optimization of the claw shape, physical models of which will be made in the next stage of research and tested in the laboratory and cowshed conditions.

Few hundred models were developed in CAD software. Models differed with the shape of a milk chamber. Differences (presented in figure 2) covered the diameter to height ratio, cross and diagonal sections and ellipticity of the horizontal section. The process of creating models and conducting simulation of flow was not labour consumptive. Thus, decision was taken to test the whole range of the designed models and based on the obtained results (velocity vectors and the distribution of liquid layers, which reflect the disturbances of the streams flowing through particular connection pipes) an initial attempt to determine an optimal shape of a claw was made.

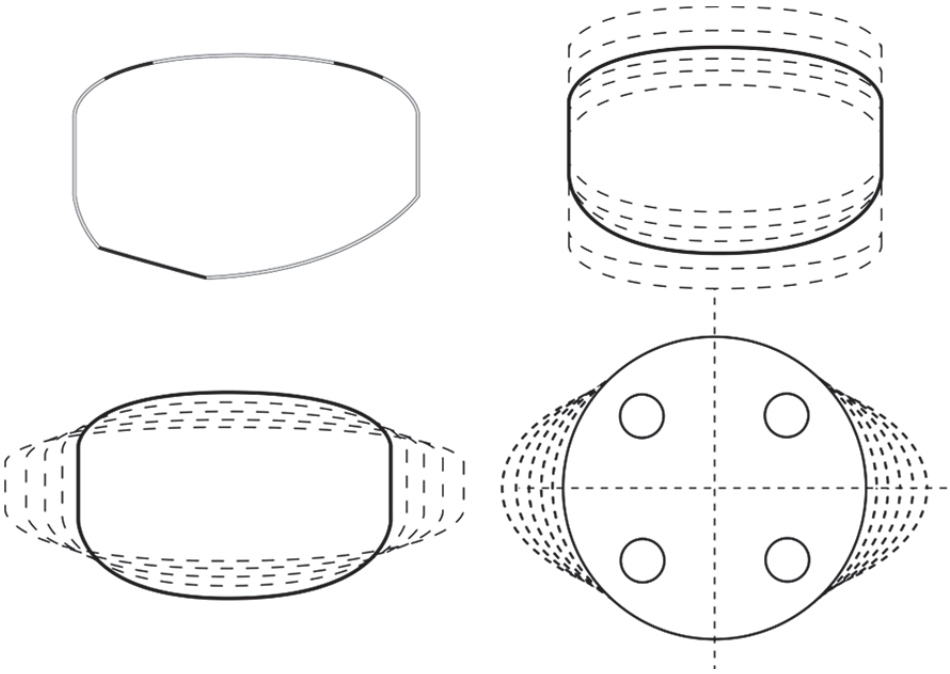

Figure 2. Schematic representation of variants of claw models used for research

The place and manner of mounting inlet and outlet connection pipes and distance of outlet connection pipes from each other at this stage of research were fixed. In the following tests, flows were also modelled including the whole range of diameters and location of connection pipes. However, results of this research are being developed.

The following were simulated:

– intensity of the liquid outflow in the amount of up to 10 kg·min^{-1},
– the level of the system under pressure within 38 and 50 kPa,
– introduction of air into a claw,
– simultaneous and alternative introduction of liquid through the inlet connection pipes.

It should be emphasised that the selected software enables provision of one medium through one inflow. In order to obtain a mixture of liquid and air, separate introduction of liquid and air through each connection pipe was simulated through designing of an additional opening for injection of air for each inlet connection pipe.

The following were analysed:

– liquid flow velocities,
– shape of streams of the flowing liquid,
– relocation of layers with various velocities,
– formation of flow disturbances caused by the claw shape,
– mutual disturbances of liquid streams from particular inlet openings,
– decrease and increase of pressures in various points of a claw.

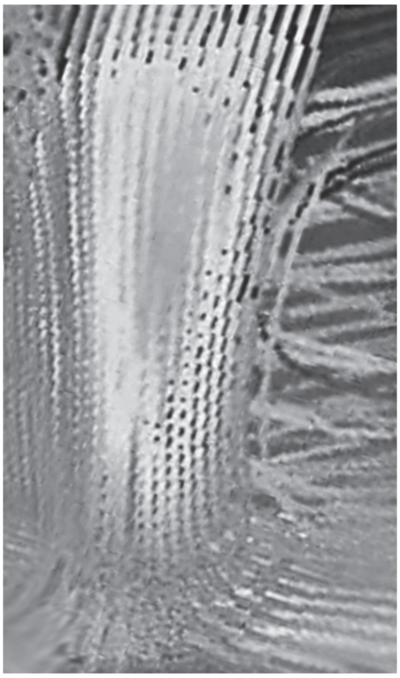

Figure 3. Fragment which illustrates liquid flow from inlet connection pipe to claw

Research results

Figure 3 shows an image of liquid flowing in through the inlet connection pipe. A disturbance caused by liquid streams mowing through the claw (flowing through the remaining connection pipes), which causes decrease of the liquid stream velocity. Light colours are layers moving with higher velocity, darker colours - with lower.

Figure 4 presents the liquid stream velocities in a claw showed on exemplary cross sections closer to the bottom part of the claw. Similarly to figure 3, lighter colours stand for higher velocity of liquid. After conversion to grey shades (for the needs of printing), the contrast was additionally increased in order to visualise differences, which in original images are visible as subtle gradients of colours. The presented example show mutual disturbances of liquid streams and the third capture presents a stream with the increased velocity in the place of an outlet connection pipe. In practice, analysis of liquid flows in claw models is the most comfortable and effective when it is carried out in a moving image with a possibility to stop the movement and watch the analysed spot from each side. Such a possibility is enabled by operation in the CFD software environment, where rotation of a 3D model is possible. Decisively lower number of possibilities of analysis of interaction between streams of the introduced media occurs at the use of a static image in the form of screen captures. Thus screen captures presented in the paper are only examples, which do not reflect the amount of information available directly in the programme.

Considerable differences between particular measurement values (models) were reported. Big differences of the liquid stream velocities in a claw within 0.05 and 1.2 $m \cdot s^{-1}$ were reported at the use of computational methods of the software for computational fluid mechanics (at the highest simulated velocities of fluid outflow *Qm*).

Differences in pressure (from the basic negative pressure established as 38-50 kPa) were within 2 kPa (decrease of pressure) to 7 kPa (increase of pressure).

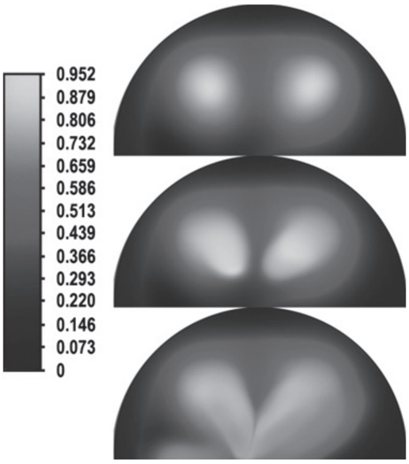

Figure 4. Halves of cross sections of claw in the part with liquid which flows out, on three levels of cross section in horizontal plane, values on the scale are provided in $m \cdot s^{-1}$

The least disturbed flow was obtained in case of claws with high factor of diameter to height which was 3-1; further decrease of the height to diameter ratio caused another increase of flow disturbances.

The use of an opening which supplies atmospheric air facilitates the flow (removal of liquid from a claw) but at the same time it causes that is decisively more violent and influences the increase of the negative pressure drops.

No considerable influence of the change of the horizontal section of a claw from a round one to an elliptic one on the analysed parameters was reported. However, it should be mentioned that differences became visible in the next stage of research (under investigation) where location of the inlet connection pipes and their mounting, which affects the direction of the inflowing liquid stream to a claw and the distance of connection pipes from each other were taken into consideration. In this case a strict correlation between direction of the liquid flowing in, angles of the claw walls, its horizontal sections and minimization of disturbances between particular streams was reported, which as a result translates into more efficient removal of liquid from a claw. The discussed stage of the research and analysis of its results allowed selection of geometric parameters of the claw model, which ensure the least disturbed liquid flow, which should translate into obtaining optimal pressure and flow parameters of milking at the following stages of research - in the laboratory and cowshed conditions.

The use of additional elements such as a deflector in a structure (extension of the discussed research, which is at the stage of the results analysis) considerably influences the flow, which becomes less violent.

Conclusion

The applied method, not extensively used in agricultural research, seems to be useful not only for the discussed modelling of flows and designing milking devices but also in a wider scope, such as e.g. designing fuel systems or hydraulic systems of agricultural machines. Additionally one may use modules which allows the analysis of flow, heat transfer and convection, e.g. for designing milk cooling systems.

It is planned to continue and extend the research covering:

– making physical models of claw and their testing in controlled laboratory conditions and in a cowshed,
– practical research (laboratory and cowshed) of machines with the designed claws,
– simulation of flows in the whole milking system during milking with the use of a higher number of milking machines and with introduction of additional disturbances.

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OPTYMALIZACJA KSZTAŁTU KOLEKTORA APARATU UDOJOWEGO Z WYKORZYSTANIEM OPROGRAMOWANIA DO SYMULACJI PRZEPŁYWÓW

Streszczenie. Celem badań była optymalizacja kształtu komory mlecznej kolektora z wykorzystaniem oprogramowania do obliczeniowej mechaniki płynów CFD. Przedstawiono wyniki symulacji przepływów cieczy w modelach kolektorów o różnych kształtach, w szczególności o różnych współczynnikach kształtu, definiowanych jako stosunek średnicy do wysokości. Analizowano prędkości przepływającej cieczy oraz wzajemne interakcje pomiędzy poszczególnymi strugami cieczy wypływającej z króćców wylotowych. Badania przeprowadzono przy wypływie cieczy od 0 do 10 $kg \cdot s^{-1}$, podciśnieniu od 38 do 50 kPa, symulowaniu wprowadzania powietrza do modelu kolektora. Stwierdzono, że najkorzystniejsze warunki przepływu osiąga się w modelach o współczynniku kształtu przyjmujących wartość około 3. Obliczone prędkości przepływu cieczy mieściły się w granicach od 0,05 do 1,2 $m \cdot s^{-1}$.

Słowa kluczowe: milking, milking machine, milking unit, claw