Design of an automated livestock milking machine: case for Zimbabwean small scale farmers

David Kulani Hlongwane
University of Zimbabwe,
Department of Mechanical Engineering,
Post Office Box MP167,
Mount Pleasant, Harare,
Zimbabwe
hlongwanea9@gmail.com

Tawanda Mushiri
University of Johannesburg,
Department of Quality and Operations Management,
Faculty of Engineering and the Built Environment,
Post Office Box APB 524 Bunting Road Campus
Johannesburg,
South Africa
tawanda.mushiri@gmail.com

Abstract

This paper document outlines the design of an automated milking machine for small scale farmers in Zimbabwe to solve the problem of low milk production. Cheap locally available materials were used to make the automated milking machine components after a detailed experiment and calculations of critical machine parts were made. The resulting parts were tested for failure using various failure testing simulations like the von Mises test. The parts were assembled and several functions of it were automated. This automated milking machine will contribute greatly to the dairy community of Zimbabwe and its economy. Recommendations for future improvements and safety precautions during machine operation for the operator and cattle are given at the end of the document.

Key words: automated milking machine, small scale farmers, simulations, safety.

1. Introduction

Milk is a liquid that female mammals produce in their mammary glands in order to feed their young. It is an important and major part of our diet associated with many health benefits because of its rich nutritional content making it one of the most consumed beverages in the world (Ware, 2017). Milk has calcium, vitamin D and potassium among many nutrients which help with bone and teeth formation, prevention of osteoporosis and muscle building. Its medicinal advantage is its ability to reduce body acidity when taken cold (Lucey, 2015). Milk can be consumed raw or in form of processed products. Milk products include butter, cheese, flavoured milk and yoghurt. It is estimated that around 6 billion people consume milk based foods all around the world (Visioli & Strata, 2014). Since milk is used to make many products it is in high demand and, with its quick expiry date, it has to be supplied regularly. In various parts of the world; goats, cattle, horses and donkeys are used as sources of milk for commercial and domestic purposes (Ulvshammar, 2008). In Zimbabwe, cattle are the main source of milk at a commercial level. For dairy farmers, it is a challenge to find and keep enough skilled cattle milking operators. With the progress that has been made in the dairy industry in the resent years, milking operators are in high demand that dairy farmers are unable to pay them enough to make large profits (Ryna & Donworth, 2013).

Hand milking is costly, time consuming and the milk is usually dirty with debris and specks of manure which reduce the quality of milk. The strain from milking a single cow is tiring and painful for those who suffer from arthritis (Freeman, 2014). With the need for better solutions for milking cattle, engineers must work with experts in animal husbandry and other scientific disciplines to come up with better solutions for these problems. This could be accomplished by making and improving milking machines. In this project, a mobile automated milking machine will be designed to do away with the problems above and to enable the average small scale farmer to own one.

1.1 Background

Milk has been a major agricultural product since people began herding cattle. With the demand of raw milk and its products rising, dairy farms are meant to meet those demands. Milk quality and quantity can be reduced by animal sickness, stress and hunger (Rhone, 2008). These setbacks are being dealt with successfully in many parts of Zimbabwe with cattle being vaccinated and treated of diseases and farmers conducting workshops on animal welfare to ensure stress free and comfortable animals. In small dairy farms, skilled hand milking operators are employed to milk the cattle. Hand milking presents problems like poor quality of milk due to dirt and manure debris in the milk. According to the Zimbabwe Association of Dairy Farmers (ZADF), in Zimbabwe educators/demonstrators conduct projects and workshops to educate and enlighten the farmers and workers on new and better ways of milking while improving the quality of the milk. There are many setbacks even with such measures being taken, some farmers are resistant to change making it difficult to increase quality of milk. Some large dairy farms in Zimbabwe have already adopted the new technology of the parlour milking system. The parlour milking system is large and effective for large herds of cattle on large dairy farms but it is not economic for small scale farms and domestic farms (Ryna & Donworth, 2013). "Zimbabwe is importing five million litres of boxed milk from South Africa leading to over $6 million leaving the country", (Chawafambira, 2013). This proves how high the demand of milk is and therefor solutions have to be provided for the small scale and domestic farmers to enable them to help meet 2018's local dairy industry target of 70 million litres market demand (Mangudhla, 2016).

1.2 Objectives of the study

- To design an automated milking machine that can milk cattle without harming their teats.
- To design an automated milking machine that can milk at most 500litres per hour while providing clean milk.
- To design a milking machine that costs less than US$300.

2. Literature survey

Cattle are the main source of milk in the world. Farmers domesticate and care for cattle for beef and milk. There are six major breeds of dairy cattle in different parts of the world which are the Brown Swiss, the Ayrshire, the Guernsey, the Holstein Milking Shorthorn and the Jersey breed (Paulson et al., 2015). Cattle are classified in different categories because of their appearance and milk production. Each type of breed produces milk of different nutritional composition. Before the milking process cattle have to be stimulated to release most of their milk from their udders (Bray & Shearer, 2014) .To get more milk from the cattle, they have to be cooperative to the milking process. Stimulation may be done by massaging, washing the cattle's teats or treating the cattle well. Before the cow is stimulated it has a pressure of about 0, 4 pounds per inch inside its udder. After stimulation the pressure increases to about 0, 8 pounds per inch (Bray & Shearer, 2014). After stimulation some of the cows' milk start leaking and dripping depending on the strength of sphincter muscle of the cow. Pressure on the outside of the teat is atmospheric pressure. During hand milking the compressive and downward forces applied to the teat by the milking operator's hand combined with the internal pressure in the udder, open the sphincter muscle allowing milk to be removed (Paulrud, 2005) .In parts of the world where there is no electricity hand milking is the most used technique of milking cattle. There are three methods of hand milking which are the thumb-in method, the pull-down method and the full-hand-grip method (Millogo et al., 2008). In the thumb-in method the teat is held on the inside of the milking operator's fingers while the thumb gently squeezes and loosens the teat muscles for the milk to come out (Vinsoun Millogo & Lennart NorellOuédraogo et al., 2011). In the pull-down method the teat is gently squeezed by the milking operator's thumb and finger while applying a downwards motion directed at the collecting bucket (Vinsoun Millogo & Lennart NorellOuédraogo et al., 2011). In the full-hand-grip method all fingers apply pressure to the teat without any downward or upward movement (Vinsoun Millogo & Lennart NorellOuédraogo et al., 2011).

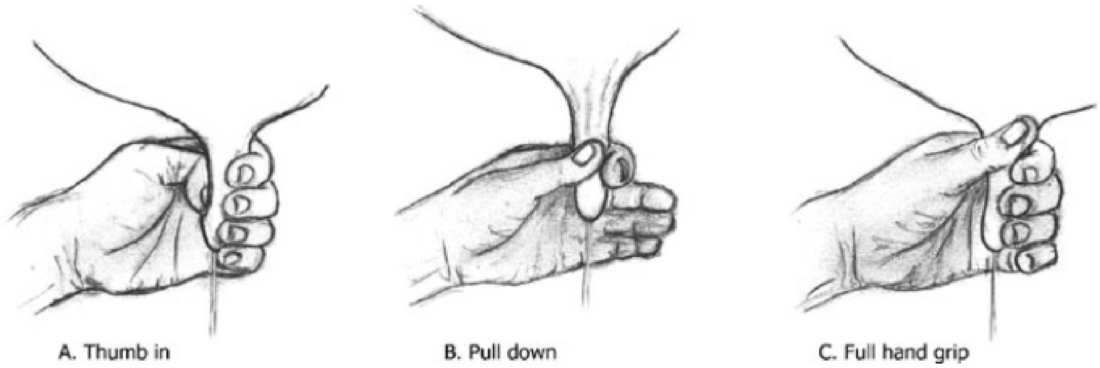

Figure 1. How milking of cows happens.

When a milking machine is used it normally applies a vacuum of 12, 5 to 15 inches of mercury outside the teat. This results in a negative pressure differential of 12, 5 to 15 inches of mercury of vacuum pressure outside the teat as compared with the 0, 8 pounds per inch of positive pressure inside the teat (Bray & Shearer, 2014). The pressure differential created is enough to loosen and open the sphincter muscle and the milk is removed even when the pressure inside the teat drops as the milk ends. Since the vacuum applied forces milk out of the teat it also forces body fluids and blood if it is uncontrolled. A constant vacuum has this effect hence the use of a double chamber cup and pulsator to prevent this damage from occurring (Bewley & Arnold, 2012). The pulsator plays the role of switching between the vacuum and atmospheric air between the liner and shell of the milking machine. When the pulsator allows entrance of atmospheric air between the milking machines' liner and shell, the liner closes below and around the cow's teat, which in turn flattens the streak canal thereby stopping milk flow (Bray & Shearer, 2014). To relieve the effects of a compressive force is applied to the teat end during its collapsed phase by the liner.

2.1. Mechanism of the milking machine

For small scale farmers in the first world countries the portable milking machines, also known as the portable milking operators, are used for milking a few cattle. Domestic farmers with about 20 cattle on their farms can't use static milking machines like the parlour systems and automated milking systems since it is not economical for them so they find the portable milking machines to be convenient and efficient for their cattle and even the sick ones in remote pens. The portable milking machine can milk cattle anywhere it is be it in the field, the barn or in pens. The portable milking machines use an oil free vacuum pump that is driven by an electric motor to provide the required vacuum for the milking system. For proper maintaining of the vacuum levels during milking, the portable milking machines come with vacuum regulators and gauges. A diesel engine may be used to provide power for the portable milking machine if the milking takes place in places with no electricity. A pneumatic pulsator is fitted in the cluster of the portable milking machine to create pulsation during the milking process. This pulsation rate can be adjusted by the user using an adjustable screw on the pulsator. The milk is collected by a sturdy stainless steel bucket during the milking process for further transportation. A steady trolley that can be easily transported has all the parts of the machine mounted on it. The trolley is usually made light and strong requiring minimal maintenance.

2.2. Challenges and Ethical Renovations for the introduced Automated Milking Systems

The benefits and problems of the automated milking systems are mainly influenced by the characteristics of the farmers and the conditions of the farm in which the technology is in use (André et al., 2007). Milking systems have proved to reduce human and animal interaction in the first world farms that have adopted the use of these milking systems and in so doing they have increased technology to animal interaction which has its up sides and down sides. According to Science and Technology studies (Hinchliffe, 1996), the introduction of new technologies in existing systems may alter these systems in complicated and unexpected ways and the introduction of the milking systems to replace the conventional way of milking unsettles the established ethical relationships on dairy farms. There is a long history of farm activities and technologies affecting farm animals and the milking systems technology is just one addition to this technological interference affecting relations between humans and animals and the ethics already established on farms (Woods, 2012). Most large dairy farmers in the first world countries have different opinions on the uses and adaptation of the milking systems technology and how they affect the existing order of their farm activities. Automated milking systems are said to give cattle freedom and choice based on their own reasoning like choosing when to be milked (Holloway et al., 2013). Some farmers see this as problematic but it is one of the reasons for the use of the automated milking systems. This is said to increase animal welfare by reducing their stress due to forced milking and by allowing free movement without bullying from other animals and herd confusion (Dohmen et al., 2010). Rounding up milked animals is easy since they are more mobile that those that have to be milked at specific times. The use of automated milking systems is argued to give farmers more time to focus on other farm projects without worrying about milking cattle since they manage their own milking (André et al., 2010) but this reduces stockmanship or the skill attained from experience with contact with animals since most proceedings are monitored from computers and this might be seen as lack of responsibility by the farmer (Wolfe, 2013).
Some cattle are stubborn and won’t go for milking voluntarily. Farmers should be in constant contact with their animals paying attention to their needs for good productivity of the animals (Driessen, 2012). According to Agric Hum Values (Holloway et al., 2013) the automated milking system is a good system for farms if it and the animals are well managed.

3. Methodology

Each component of the milking machine was designed after all necessary calculations were made. Much focus was put on the selection of the vacuum pump and the design of the vacuum buffer tank since it is critical to avoid harming the cattle. Locally available materials were chosen for the machine parts to reduce the overall cost of the milking machine. The selection of A36 steel for the frame is attributed to its relatively low cost. Stainless steel was selected for the vacuum buffer tank because of its resistance to stain and corrosion. Polycarbonate material was selected for the milk collector because of its temperature resistance and impact resistance. After experiments and calculations the following parameters for the machine parts were found,

Vacuum pump with a minimum power of 0.55kW

Vacuum buffer tank of diameter = 0.15m
thickness= 0.004m
length = 0.34m

Milk collector(bucket) of thickness = 0.007m
base diameter = 0.38m
mouth diameter = 0.19m

Teat cups of opening diameter = 0.02m
thickness = 0.001m

Frame of lenght = 0.7m
width = 0.04m
depth = 0.04m
thickness = 0.004m
height = 0.7m

The resulting assembly of the automated milking machine is shown in table 1.

Table 1. Parts of a milking machine

Balloon Number	Part Number
1	Pulsator tube
2	Vacuum regulator
3	Cluster
4	Teat cup
5	Milk tube
6	Bucket lid
7	Bucket handle
8	Milk collector
9	Wheel
10	Vacuum tube

11	Stand
12	Dry vacuum pump
13	Machine frame
14	Vacuum buffer tank
15	Machine handle
16	Pulsator

Figure 2. Milking machine

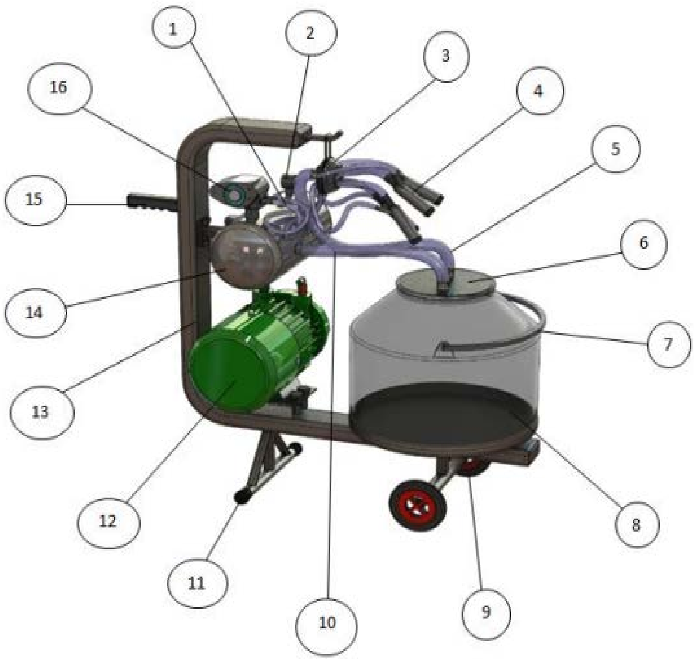

Figure 3. Parts of the machine identified.

4. Results and discussions

The costs of the readily made machine components like the bolts and vacuum pump were found from research. The grand total of making the automated milking machine is $298.24 and is within the intended $300 objective. The machine works as follows. The vacuum pump is switched on and left for a few second to build up a vacuum in the vacuum buffer tank. The teat-cups are connected to the cow's teats and milking begins. When the machine switches off according to automation commands the milk collector is offloaded.

5. Recommendations and Conclusion

5.1 Design Considerations

This section highlights the possible future expansion of the scope of this automated milking machine by additions of other functions that could make it more efficient and improve its ergonomics.

5.2 Self-Cleaning System

A self-cleaning system should be installed on the machine to clean the areas of the machine that can't be reached by human hands like the inside of the machine's pipes, cluster and teat cups for effective and easy cleaning of the machine before and after each operation.

5.3 Safety Guards

Safety guards should be designed to protect users from accidents that may be encountered when contact is made with the vacuum pump while in operation.

5.4 Cleanliness and Maintenance

The teat-cups and cluster of the machine should be cleaned before and after every milking operation to prevent infections in the cattle's udders that could cause mastitis. The milk collector should be cleaned regularly to ensure milk cleanliness on every milking operation. The vacuum pipes should be maintained regularly to make sure there are no leaks which reduce the efficiency of the machine and contaminate the vacuum and possibly the milk.

5.5 Conclusion

The automated milking machine was successfully designed with the machine made up of locally available materials at affordable prices that will enable small scale dairy farmers to improve their milk productivity and profits. The cost analysis showed that the machine is well within the aimed budget of $300. The solidworks analysis of the automated milking machine showed that the milking machine has a weight of less than 50kg which is well within the intended objectives. The objectives of the project were well met but it is only until the prototype is made and well adjusted, that this project's purpose and impact will be recognized by the small scale dairy farmers and the county's economy.

Bibliography

André, G. et al., 2010. *Increasing the Revenues from Automatic Milking by Using Individual Variation in Milking Characteristics.* J. Dairy Sci.

André, G., Ouweltjes, W., Zom, R.L.G. & Bleumer, E.J.B., 2007. Increasing economic profit of dairy production utilizing individual real time process data. In S. Cox, ed. *Precision*

Livestock Farming. 7th ed. Wageningen: Wageningen Academic Publishers. pp.179-86.

Bewley, J. & Arnold, M., 2012. *Recommended Milking Procedures for Maximum Milk Quality*. LEXINGTON: University of Kentucky College of Agriculture University of Kentucky.

Bray, D.R. & Shearer, J.K., 2014. *Milking Machine and Mastitis Control Handbook*. Florida: IFSA Extension University of Florida.

Chawafambira, F., 2013. *Zim spends $6m on milk imports*. [Online] Harare Available at: https://www.dailynews.co.zw/articles/2013/12/04/zim-spends-6m-on-milk-imports [Accessed 6 august 2017].

Dohmen, W., Neijenhuis, F. & Hogeveen, H., 2010. Relationship between udder health and hygiene on farms with an automatic milking system. *Journal of Dairy Science*, 93, pp.4019–33.

Driessen, C., 2012. Farmers engaged in deliberative practices. *An ethnographic exploration of the mosaic of concerns in livestock agriculture*, 25(2), pp.163-79.

Freeman, A., 2014. Hand or Machine Milking? *Cattle Forum*, (Technical Article).

Hinchliffe, S., 1996. Technology, power, and space—The means and ends of geographies of technology. *Environment and Planning D: Society and Space*, 14(6), pp.659–82.

Holloway, L., Bear, C. & Wilkinson, K., 2013. Re-capturing bovine life. *Robot-cow relationships, freedom and control in dairy farming*, (6).
Holloway, L., Bear, C. & Wilkinson, K., 2013. *Robotic milking technologies and renegotiating situated ethical relationships on UK dairy farms*. UK: Springer Science+Business Media Dordrecht University of Hull.

Lucey, J.A., 2015. *Raw Milk Consumption*. New York: Wolters Kluwer Health.

Mangudhla, T., 2016. Dairy pours US$6m into expansion projects. *Zimbabwe Indepent*, 26 august. p.4.

Millogo, V., Ouédraogo, G.A., Agenäs, S. & Svennersten-Sjaunja, K., 2008. Survey on dairy cattle milk production and milk quality problems in peri-urban areas in Burkina Faso. *African Journal of Agricultural Research*, 3, pp.215-24.

Paulrud, C.O., 2005. Basic concepts of the bovine teat canal. *Veterinary Research Communications*, 29, pp.215-45.

Paulson, J., Salfer, J., Newell, S. & Santi, E., 2015. *Learning About Dairy*. Minnesota: Midwest Dairy Association University of Minnesota.

Rhone, J.A., 2008. *Factors Affecting Milking Yield, Milk Fat and Milk Quality*. Dr Thesis. Florida: University of Florida University of Florida.

Ryna, T. & Donworth, J., 2013. Milking Facilities. In Ryna, T. & Donworth, J. *Agriculture and Food Development Authority*. pp.126-27.

Ryna, T. & Donworth, J., 2013. Milking Facilities. *Agriculture and Food Development Authority*, pp.127-28.

Ulvshammar, K., 2008. Milk and Meat producing animals in the world. *SLU*, Uppsda.

Vinsoun Millogo & Lennart NorellOuédraogo, G.A., Svennersten-Sjaunja, K. & Agenäs, S., 2011. Effect of different hand-milking techniques on milk production and teat treatment in Zebu dairy cattle. *Trop Anim Health Prod*, 44, pp.3-4.

Visioli, F. & Strata, A., 2014. Milk, Dairy Products, and Their Functional Effects in Humans. *A Narrative Review of Recent Evidence*, American Society for Nutrition.

Ware, M., 2017. *Health Benefits and Nutritional Information*. [Online] Available at: http://www.medicalnewstoday.com/articles/245588.html [Accessed 7 august 2017].

Wolfe, C., 2013. *Before the law: Humans and other animals in a biopolitical frame*. Chicago: University of Chicago Press University of Chicago.

Woods, A., 2012. Rethinking the history of modern agriculture:British pig production. *Twentieth Century British History*, 23(2), pp.165-91.

Biographies

David k Hlongwane registered for the ZIMSEC O' level exams in 2012 and passed the science subjects with 'A's. He then continued his A' level classes and studied mathematics, physics and chemistry in 2013. He registered with ZIMSEC for his A' level exams in 2014 and passed the science subjects. Upon receiving his results in 2015, he applied for temporary teaching at Lushonkwe Secondary School where he taught mathematics, biology and integrated science to ZJC and O' level students until 2015. With an interest in the mechanics of machines, he commenced his tertiary education at the University of Zimbabwe to attain a BSc. honours degree in mechanical engineering. He has completed twenty six modules of which he passed.

Dr. Tawanda Mushiri received his Bachelor of Science Honors Degree in Mechanical Engineering (2004-2008) and a Masters in Manufacturing Systems and Operations Management (MSc. MSOM) (2011-2012) from the University of Zimbabwe, Harare, and a Ph.D. from the University of Johannesburg, South Africa (2013-2017). He also obtained a Certificate with Siemens in Programmable Logic Controllers in the year 2013 where he worked with SCADA and PLC Programming. His doctorate involved fuzzy logic and automated machinery monitoring and control. Currently, he is a Senior Lecturer and Senior Research Associate at the University of Zimbabwe and University of Johannesburg, respectively. In the past (2012-2013), he has also lectured at the Chinhoyi University of Technology, Zimbabwe, lecturing mechatronics courses. He has also been an assistant lecturer for undergraduate students at Chinhoyi University of Technology, tutoring advanced manufacturing technology, robotics and machine mechanisms.