Optimal Strategies to Relieve Tissue Congestion

December 12, 2007

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Client: Professor Doug Reinemann

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Table of Contents

Abstract:

Externally applied pressure can be used to facilitate blood circulation and relieve congestion of soft tissues. This technique has been used on people with circulatory impairment as well as during the milking process for animals. This project explores optimal strategies for congestive relief using biophysical principles.

Milking machines utilize a vacuum to remove milk from the cow's udder. Due to this applied suction force, fluids inside the teat collect at the tip. This pooling effect leads to congestion, which can cause discomfort, reduced milking rate, mastitis, and hyperkeratinization of the surrounding tissue.

The client has requested the design of a new milking machine attachment that reduces the negative symptoms of congestion and maintains a high milking rate. After research regarding the effects of fluid collection in soft tissue and the mechanism of existing milking machines, it was decided that a positive pressure massage period following milking would be most practical for congestion relief on most dairy farms.

Three preliminary design alternatives were created; the organization and ranking of criteria in a design matrix was used to score each design, and the final design was selected. A prototype was constructed, and initial testing of the prototype was conducted. However, additional testing and analysis are required.

Problem Statement:

The current design of automated milking machines relies on a strong vacuum force to extract milk from the sinus udder. As a side effect, blood and interstitial fluids collect in the teat causing tissue congestion and at times, chronic edema. Tissue congestion in cows is not only uncomfortable, but can also lead to canal constriction causing reduced milking speed, bacterial infection, and hyperkeratinization. The newly designed milking machine attachment must extract milk at a comparable rate while simultaneously providing compression of the teat to better reduce tissue congestion.

Background:

The teat of a dairy cow has several important parts to consider. The inner core is the expandable sinus cavity where milk is stored. To extract milk from this sinus cavity, farmers attach teat cups, which are connected to the milking machine. These cups are essentially small but powerful vacuum hoses.

Surrounding the sinus cavity is a very strong network of blood vessels, naturally adapted for the stress of calving. Unfortunately, they are not well adapted to the unnatural stress of the vacuum exerted by the teat cups. After a number of milkings, blood and interstitial fluid begins to accumulate at the tip of the teat, caused by the vacuum of the cups. If this accumulation persists, the vessels and channels at the bottom of the teat may become congested, and more serious problems arise over time.

The earliest clue of congestion is a reduction in the milk flow rate (the amount of milk extracted by the cow per unit time). Unfortunately, this is also an early sign of many other problems, so farmers usually continue milking until a better indicator can positively be identified. A cow may become uncomfortable as well. Bucking, shaking, and excess mooing usually reveals the cow's discomfort or pain. This is obviously undesirable for the cow, but it also makes it harder for the farmer to manage the cow efficiently.

If nothing is done early to alleviate these symptoms, more severe consequences can take hold. The very bottom of the teat includes the canal, which is directly connected to the milk sinus cavity above. Muscles surrounding the canal allow the cow to keep the canal closed, preventing milk from spilling but also foreign agents from entering the cavity. Congestion partially inhibits the closing of the canal, and can therefore lead to spilled milk but, more seriously, to bacterial infection.

Another critical ailment of congestion is hyperkeratosis. This occurs when the tissue becomes stressed and strained due to excessive stretching of the sensitive skin caused by strong vacuum forces. The area becomes hardened, very similarly to calluses on human hands after manual labor.

Figure 1: Teat-end hyperkeratosis, where the area is hardened due to excessively applied stress.

In the most severe of cases, fluids may even collect outside of channels. This is called udder edema, and it is a very serious condition of congestion. When this happens, the farmer must relieve the cow of milking and loses production efficiency.

Current Milking Machines:

Today's basic milking machine consists of the following components: claw, four teat cups, milk and vacuum hoses, several connection hoses, milk and vacuum pipes, and a pulsator.

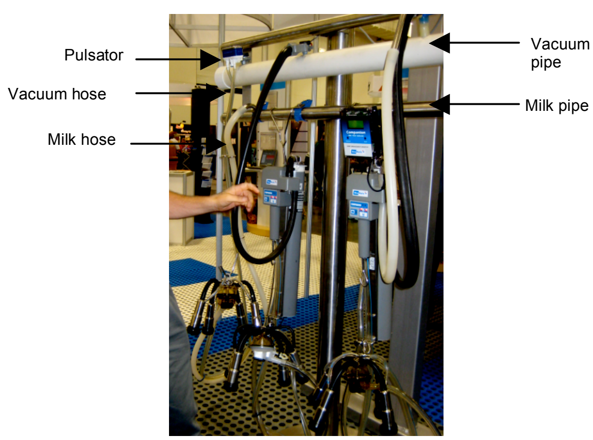


Figure 2: Milking machine set-up

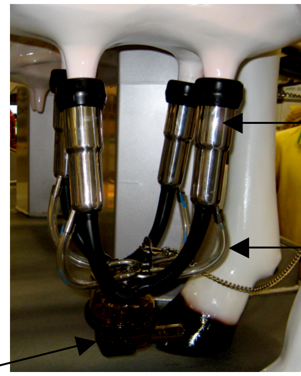


Figure 3: Claw and teat cups

The claw is a round, hollow device, generally made of a rigid material such as plastic or metal. It is responsible for collecting milk extracted from the cow during the milking process. The claw is also the component that ties all other components together. Attached to the claw are both the vacuum and milk hoses. These hoses provide the necessary vacuum pressure of 32 to 40 kPa to extract milk from the cow. Both the vacuum and milk hoses are directly connected to their respective vacuum and milk pipes, the sources of the vacuum pressure. The suction created by the vacuum and milk pipes runs through the vacuum and milk hoses to the claw and then to the teat cups.

The vacuum pressure originating in the milk pipe flows directly to the inner liner of the teat cup by passing through the claw. This vacuum is held constant at 32 to 40 kPa for the entire 4 to 5 min milking period. The vacuum helps to milk the cow as well as keep the teat cup attached to the teat. The vacuum pressure originating in the vacuum pipe flows from the pipe to the pulsator. The pulsator is connected to both the vacuum pipe and the vacuum hose. Acting as a three-way valve, the pulsator connects the vacuum hose to either atmospheric pressure found in the pulsator chamber or vacuum pressure from the vacuum pipe. The pulsator is also regulated to alternate between atmospheric pressure and vacuum pressure. The alternating pressures create a cycle that occurs once every second. The vacuum hose connects to a small four-way connector at the top of the claw. The connector diverts the pressure in the vacuum hose to all 4 teat cups. The diverted pressure is connected to an opening in the outer shell of the teat cup, subjecting the area between the inner liner and outer shell of the teat cup to either atmospheric or vacuum pressure.

As illustrated by the milking cycle (Figure 4), a constant vacuum force of 32-40 kPa is on for 2/3 of a second then relieved for 1/3 of a second. This on-off cycle is repeated once every second throughout the 4 to 5 minute milking process. This periodic compression minimizes strain on the teat caused by the vacuum force and works as massage to induce circulation so that blood and other interstitial fluids migrate upward toward the teat sinus and udder.

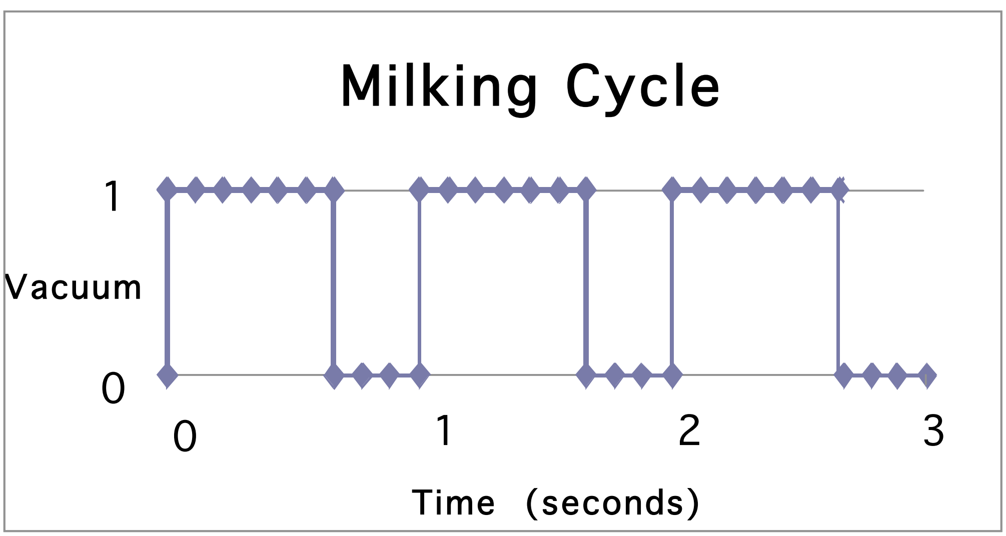


Figure 4: Graphical depiction of milking cycle

The sequence shown in Figure 5 is a cross-section of the teat in the liner during the milking cycle. The first stage shows the liner fully compressed around the teat, applying pressure solely to the tip. The middle stage shows the liner fully open and milk extracted from the teat through the canal. The final stage shows the liner fully closed again.

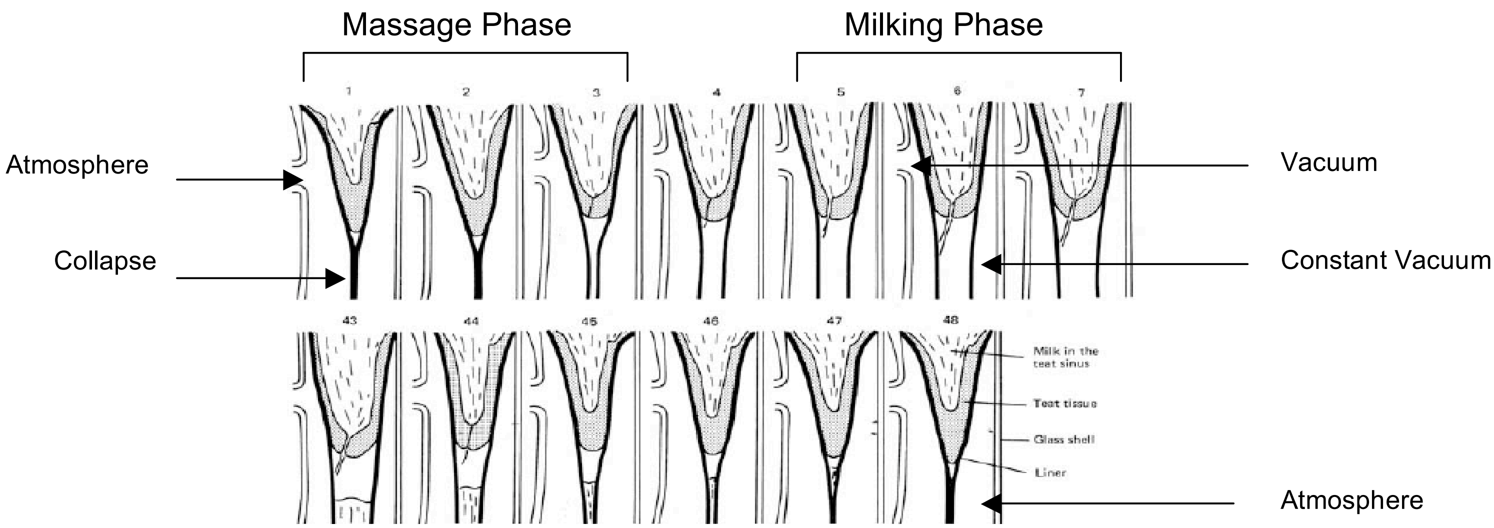
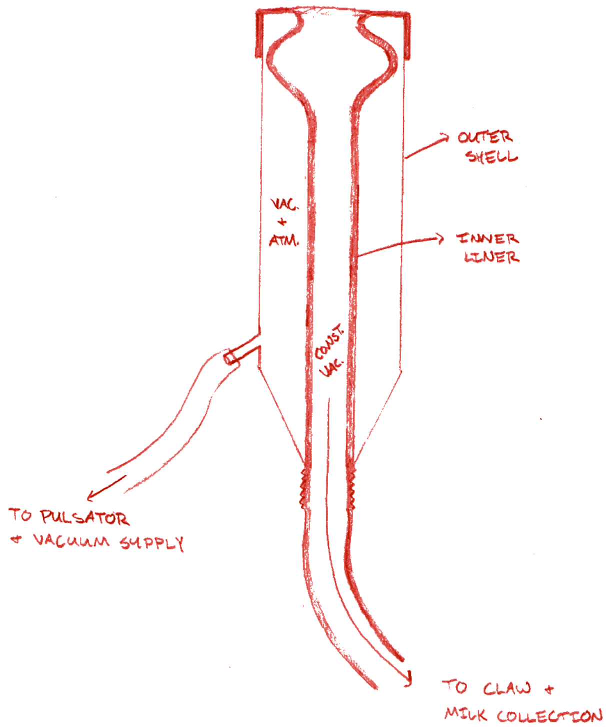


Figure 5: Cross section of the teat in the liner during the milking cycle sequence. [2]

During the milking phase, both the inner liner, and the area between the inner liner and outer shell are subjected to equal vacuum pressure in the range of 32 to 40 kPa. Using equal pressure in both areas keeps the inner liner open, allowing milk to be pulled downward from the udder through the teat and into the claw. The milk in the claw is then removed by the milk hose to the milk pipe where it is carried away to a different section of the milking parlor. This phase lasts for 2/3 of every second during the milking process.

During the massage phase, the inner liner remains under a vacuum pressure of 32 to 40 kPa while the area between the outer shell and inner liner is subjected to atmospheric pressure. The pressure difference causes the inner liner to collapse around the end of the teat. The collapsing of the liner provides the teat with a brief massage that helps to relieve tissue congestion. This phase lasts for 1/3 of every second during the milking process.



<u>Figure 6</u>: Forces exerted on teat cup during milking

Design Requirements:

The primary criteria provided by Dr. Reinemann are that the design reduces the symptoms of congestion and maintains a high milking rate for economic and efficient production. Additionally, the design must be intuitive and convenient for the dairy farmer to use, as the milking process is already time-consuming. Ideally, an addition to existing milking machines would minimize cost and would be simple to implement in existing milking parlors. Both the device and the milking process must be sterile to ensure milk quality and reduce the risk of bacterial infection of the teat. Finally, the device must not exceed 2.3 kg and must utilize a constant vacuum pressure of 32-40 kPa during milk extraction. (See Appendix for complete PDS)

Preliminary Design Ideas:

In brainstorming methods to relieve congestion, several ways were explored to increase circulation, including compression, heat, and oral and topical medications. It was concluded that compression would be most feasible and effective as applied to the given problem statement. The integration of a recovery massage period post-milking while cows are still in the milking parlor enhances existing compression cycles with positive pressure.

This recovery massage period will be executed by a fully automatic addition to existing milking machines so that no additional work is required of the dairy farmer. Also, by utilizing the time following milking, while cows are still in the milking parlor, the milking process is optimized and no extra time investment is necessary in order to benefit from this treatment.

The main goal of creating three design alternatives is to reduce tissue congestion in the teat end. By providing the teat with a massage during several minutes of downtime post-milking, congestion relief can be maximized. All three alternatives apply positive pressure to the teat in order to provide a compressive massage that induces blood circulation. In order to apply positive pressure, the vacuum in both the inner liner and area between the inner liner and outer shell would need to be removed or reduced in order to avoid an excessive pressure differential. Completely removing the vacuum in the inner liner causes the milking unit, claw and four teat cups to fall off the cow. For a compressive massage to be applied, the milking unit would need to remain on the cow after the inner liner vacuum has been removed. This obstacle became the primary focus of the three design alternatives.

Design 1: Udder Vacuum

The first design alternative is the udder vacuum design, shown in Fig. 7. This design revolves around additions to the original milking machine components. For the udder vacuum to function properly, several new components must be added; a positive pressure pipe, second pulsator, positive pressure hose, additional connection hoses, two more four-way connectors, second opening in the teat cup outer shell, on-off valve, air bleed, and most importantly suction cups.

The second pulsator is connected directly to the positive pressure pipe. Again, the pulsator acts as a three-way valve connecting the positive pressure hose to either positive or atmospheric pressure. It also regulates the alternating sequence between the two pressures using the same time cycle from the milking process itself.

The positive pressure hose then runs alongside the vacuum hose down to the claw where it is attached to a four-way connector. The connecter diverts the pressure to the 4 teat cups through a second opening in the outer shell. In order to remove the inner liner vacuum, the vacuum hose is spliced near the claw, using an on-off valve to divert air flow between both sections of the vacuum hose. The spliced section of hose connects to a third four-way connector that diverts vacuum pressure to each of the teat cups by connecting to the suction cup portion. Due to the larger area of the suction cup, an air bleed is placed in the spliced section of hose to reduce the vacuum pressure to a much lower value. By increasing the area, a lower pressure can be used to provide enough force to keep the teat cups attached to the cow.

After milking has finished, the on-off valve turns on the vacuum in the suction cup but not in the inner liner of the teat cup. Alternating atmospheric and positive pressure is then applied to the area between the outer shell and inner liner, causing the inner liner to open and close around the teat, massaging it, and relieving congestion.

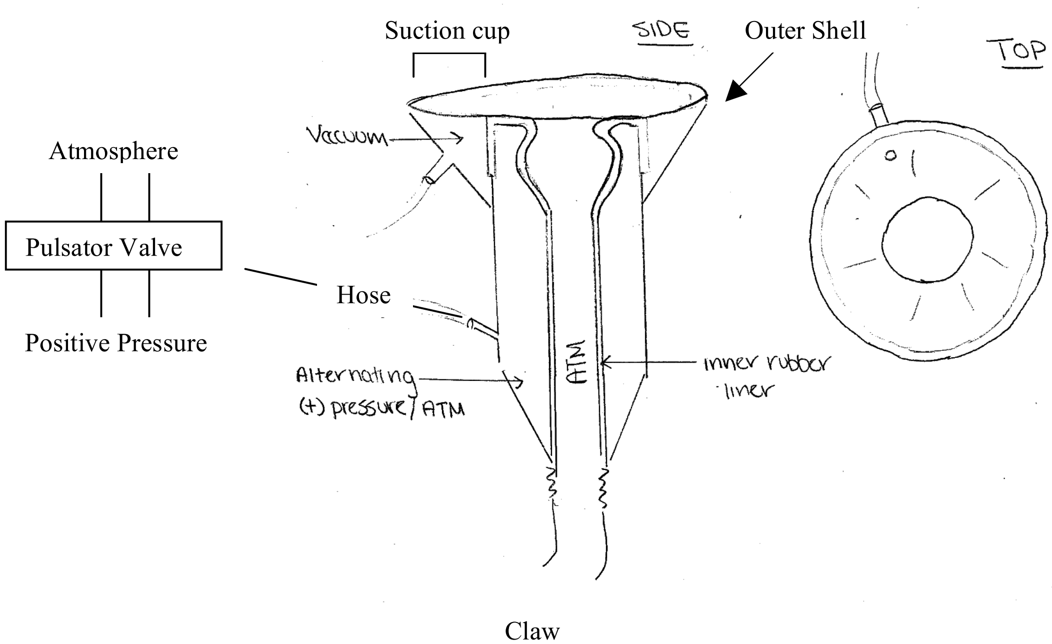


Figure 7: Udder vacuum design

While congestion of the teat may be relieved, the possibility of congesting the tissues in the udder should be considered. The extra chamber, with its plunger-like shape, would apply the negative pressure on a much wider surface area than the teat. A wider surface area allows less suction to be used. Additionally, the udder wall can withstand much more vacuum pressure than a teat. Therefore, congestion in the udder walls should be minimal.

This design allows for tissue congestion relief using positive pressure massage to be maximized because there is no vacuum force on the teat; vacuum only exists between the outer shell and the udder. The addition of this vacuum, however, makes this design very complicated due to numerous parts and extra hose connections.

Design 2: Reduced Vacuum Liner

The second design alternative utilizes the already present vacuum force to keep the milking claw attached to the cow. As with the other designs, postmilking tissue congestion relief will be accomplished through an alternating compressive force applied to the teat. The application of a minimal vacuum pressure in each of the teat cups during postmilking massage affords a simple and reliable way to keep the teat cups attached to the cow during the mentioned postmilking massage. This design would be almost identical to current teat cups already used in dairy farms, except for a few minor changes. The difference would be the creation of a positive pressure main in the milking parlor, accompanied by pulsator valves at each milking station.

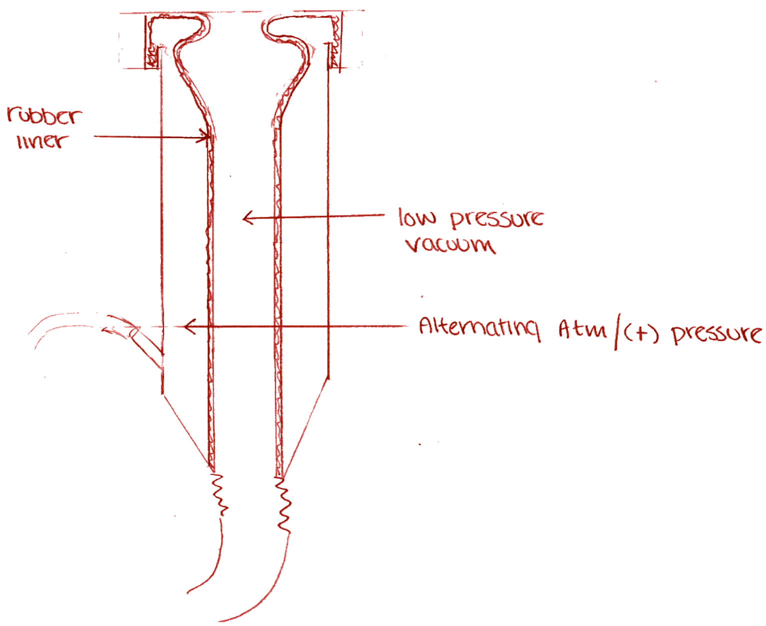


Figure 8: Reduced liner vacuum design

The alternating positive/atmospheric pressure would be fed from a parlor PVC pipe through the same pressure line currently attached to the outer chamber of the teat cup. The addition of pulsator valves to the positive pressure chamber would allow for this pulsation. With the addition of clamps and valves, leakage will be minimized while utilizing the majority of the pre-existing airways.

With a reduction in the weight of the milking claw, very low vacuum pressure will be able to accomplish the task of keeping the assembly attached to the udder, while the alternating pressures apply the massage. Using the weight of the milking claw along with coefficients of friction a reasonable vacuum pressure per teat cup will be decided upon before testing at the UW milking parlor to ensure it allows for the teat cup to remain attached properly.

This design differs from the previous in that it is much less mechanically complicated and utilizes the current machine characteristics much more efficiently. The simplicity of this design will be ideal for farmers and will allow for it to be easily integrated. Since the teat is still subjected to a slight vacuum, the degree of congestion relief may be reduced. Additionally, the distinct similarities between this design and the current milking device will mean that no durability or implementation problems should arise, not to mention farmers will be satisfied using a piece of equipment they are familiar with.

Design 3: Support Arm

The third design alternative uses a mechanical support arm to relieve the weight of the teat cups and claw in order to keep the teat cups attached to the cow, see Fig. 9. As with the other designs, postmilking tissue congestion relief will be accomplished through an alternating compressive force applied to the teat. The use of a support arm to relieve the weight of the milking claw assembly will provide a high level of tissue congestion relief with the massage technique established since no vacuum pressure is being applied to the teat or the udder. To apply this compressive massage, this design would use the same teat cup and pressure line layout as the previous design, without the slight vacuum in the inner liner.

The support arm in this design would rotate to access the udder of the cow from her side. It would hold the entire weight of the claw and teat cups during the postmilking massage by supporting from below. During milking this arm would allow the claw to hang and after milking it would rise slightly in order to hold the teat cups on to the teats without any outside assistance.

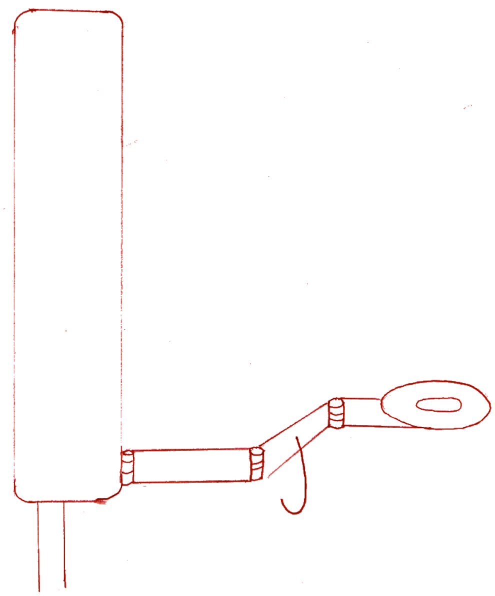


Figure 9: Support arm design

The use of a support arm as described requires a herringbone parlor. A herringbone parlor is one in which cows stand on an elevated platform in an angled or fishbone fashion facing away from the operator. This exposes enough of the back half of the cow to allow access to milk her from the side and room for an arm type detacher and associated equipment as mentioned to be attached to the cow. Despite the fact that herringbone parlors are not popular among larger dairy farms, they are the most common parlor type in the US for smaller scale dairy farms (under 24 cows). This would allow our design to be easily integrated in said parlors.

With the elimination of any vacuum force keeping the milking assembly attached to the cow during post milking, tissue congestion relief is maximized by only applying the advantageous pulsating compressive massage. However, this support arm design may be difficult to implement in larger farms where space is limited.

<u>Design Matrix</u>:

	Congestion Relief (50)	**Attachment Support** (15)	**Ease of Use** (15)	**Durability** (10)	**Cost** (10)	**TOTAL** (100)
Udder Vacuum	40	15	10	5	5	75
Reduced Liner Vacuum	35	10	15	10	10	80
Support Arm	40	5	5	5	5	60

<u>Figure 10</u>: Design matrix used to evaluate three design ideas

As shown in Fig. 10, our team picked the best design using a weighted design matrix with five main criteria. The most important and highest weighted criterion is congestion relief, that is the ability of the design to relieve tissue congestion in the cow's teats after milking. Since all three designs utilize the same method of congestion relief (positive pressure massage), they all scored about the same in this category. The reduced liner vacuum idea scored slightly lower than the other designs because a small vacuum will still be applied on the teats to keep the device attached, and this may reduce the potential for congestion relief. To counteract this, higher positive pressure will be applied.

The second criterion is attachment support. If the vacuum is reduced or turned off, it is very important to keep the milking unit secure and in place. The udder vacuum received the highest score in this category because it has its own vacuum source and would provide a very strong and secure support for the milking unit. The reduced vacuum scored lower because there is a greater chance that the unit could fall off while the vacuum is not providing as much suction as normal. The support arm received the lowest score in this category because the device is holding up the bottom of the milking unit with no suction, so if the cow moved, the device could easily fall off and no longer provide congestion relief to the cow.

Ease of use is the third criterion we used to evaluate the ideas. This refers to the complexity of the design as well as how convenient it is for the farmer to use. The reduced liner vacuum scored the highest because the design basically utilizes the existing system except for the addition of the positive pressure line. Therefore, it will be easy for farmers to add to their existing equipment and has a very simple design. The next highest was the udder vacuum, which has the added complexity of another vacuum, more tubing, and more connections needed. It could be added to existing equipment, but it would make things more complicated for dairy farmers and take longer to integrate into milking parlors. The support arm received a low score in this category mainly because it could not be used in most parlors due to lack of space. Also, the farmer would need to adjust height of the arm for each cow, which would take more time and effort than is probably desired.

The fourth consideration is durability, which is important because the designs will be used in a farm environment, and may be subjected harsh conditions, as well as wear and tear from every day use. The reduced liner vacuum again scored the highest because of its utilization of existing parts, which are already designed to be durable in this environment. The udder vacuum and support arm both received lower scores because of the addition of extra parts, which will have to be made extremely durable and will have additional pieces that need to be maintained.

The final criterion is the total cost of implementing the design. The reduced liner vacuum would cost the least to integrate into existing milking equipment, so this design received the highest score. Both the udder vacuum and support arm would cost considerably more because of the extensive amount of extra parts needed by the farmer to implement these systems.

After weighting the scores and computing the totals, the reduced liner vacuum came out ahead of the udder vacuum and support arm. This is mainly due to the convenience and simplicity of the design, which will make it more appealing to dairy farmers.

Final Design:

Keeping client requirements, design constraints, and the overall goal of relieving tissue congestion in mind, our team was able to design not only a functional, but also an effective final prototype. The final prototype utilizes alternating positive and atmospheric pressure massage to relieve tissue congestion. Alternating pressures cause the inner liner of the teat cup to collapse around the teat, forcing the congestion back up the teat sinus toward the udder.

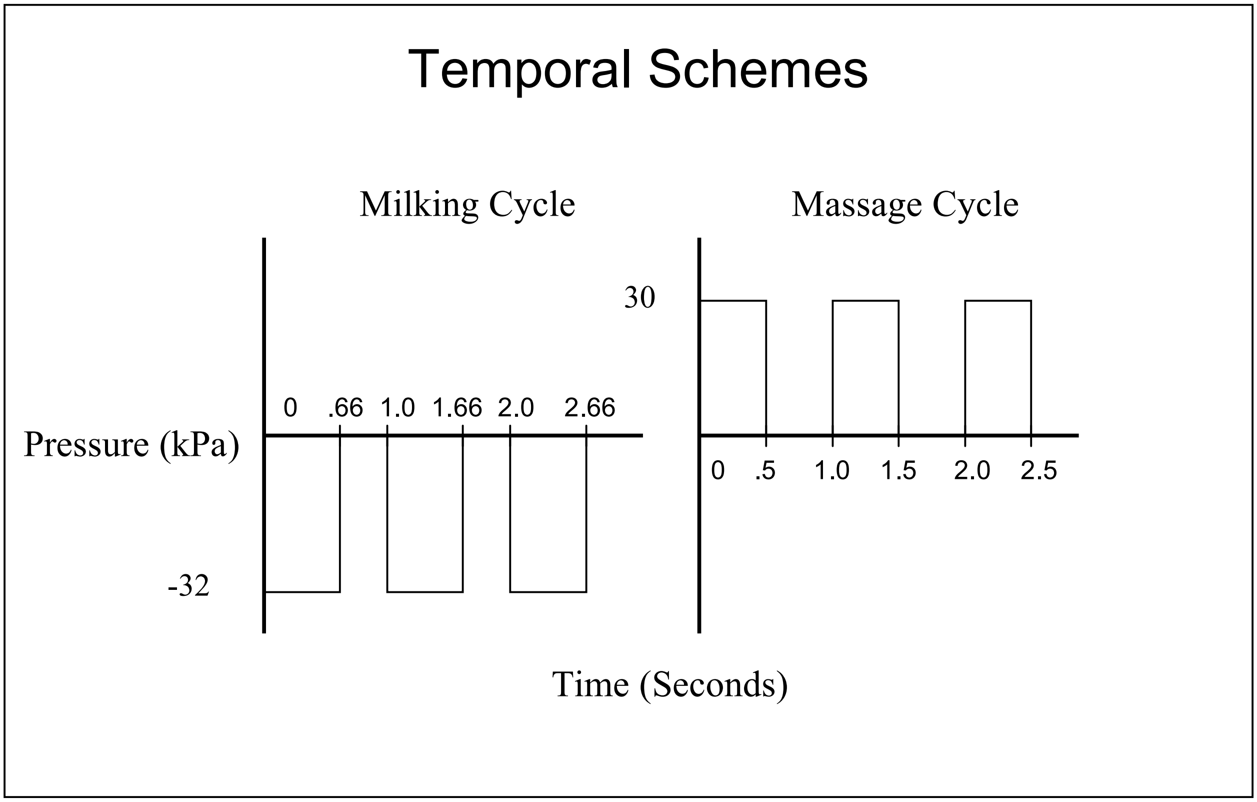


Figure 11: Temporal schemes of milking and massage cycles

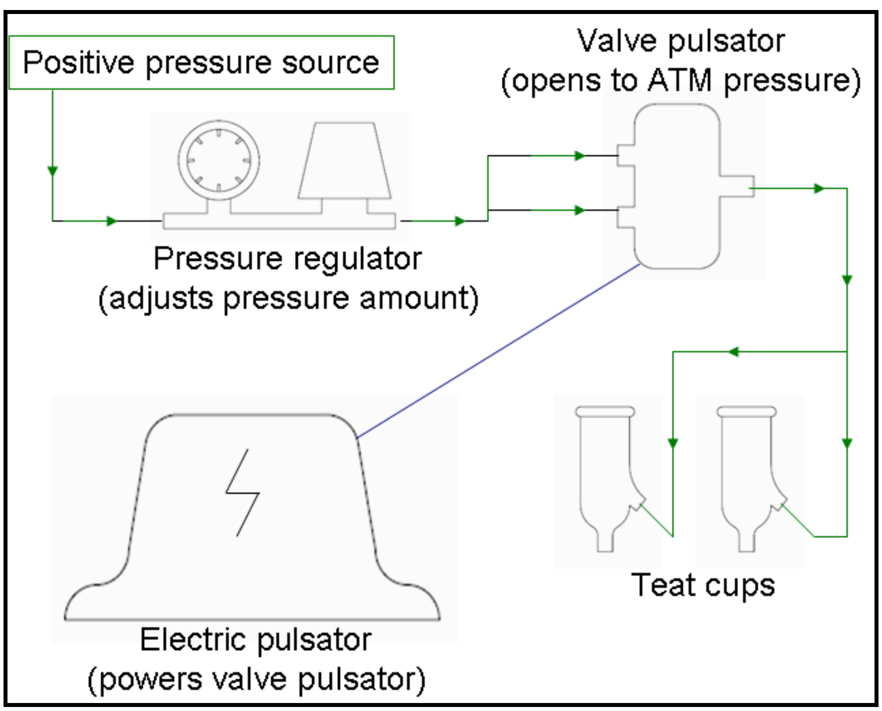
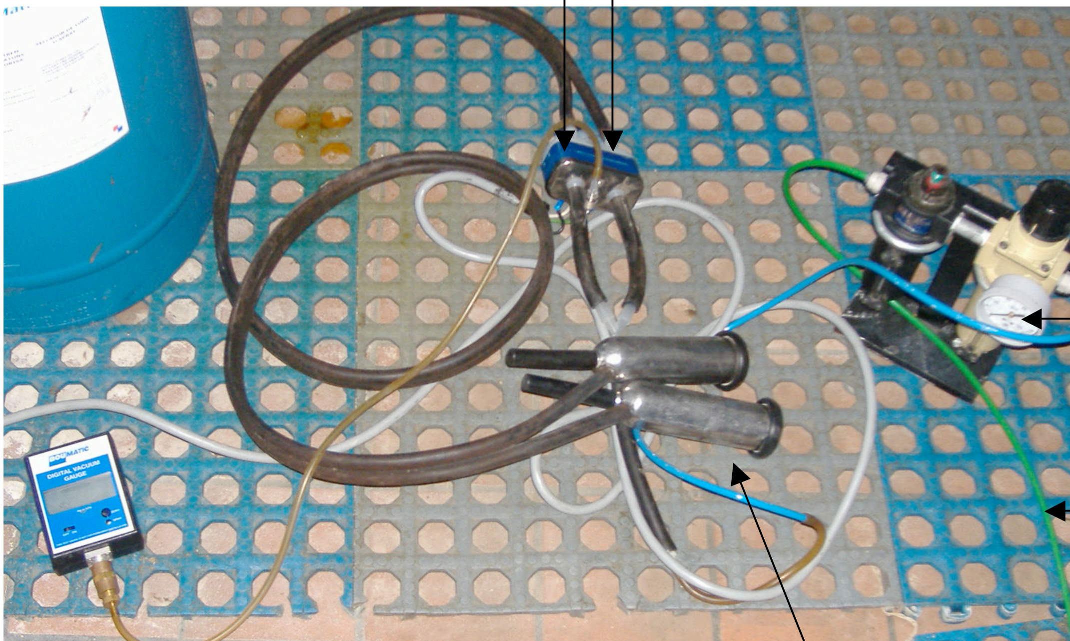


Figure 12: Prototype schematic



<u>Figure 13</u>: Prototype

For the final prototype to function properly, it needs to be directly connected to a positive pressure source. The positive pressure source, in most cases, is a positive pressure line running through the milking parlor. However, it is also possible to use a tank of compressed air or an air compressor. The positive pressure then flows from the source to the sink, the teat cups, but must pass through several components on the way. After exiting the positive pressure line, air flows through a hose to the pressure regulator. The pressure regulator is used to adjust the positive pressure allowed to reach the teat cups to be used in the massage. The pressure is adjusted by a manual dial on the regulator that corresponds to a reading on the pressure gauge. Theoretically, any pressure can be used so long as it is great enough to collapse the inner liner of the teat cups, but it is also important that the pressure does not cause the cow any discomfort. Next, air flows to the valve pulsator which is regulated by the electronic pulsator. The valve pulsator is simply a two-way valve that allows either positive pressure or atmospheric pressure to flow into the teat cups. As previously stated, the electronic pulsator regulates the opening and closing of the valve pulsator.

The final prototype alternates positive pressure between each teat cup and is applied for 0.5 s and removed for 0.5 s (allowing atmospheric pressure to reach the teat cups) every second for the desired length of massage. It is important to note that this timing cycle can be easily adjusted through the electronic pulsator. Finally, air flows from the valve pulsator to the teat cups where the massage is applied to the cow's teats.

The goal of positive pressure massage treatment is to induce recirculation of blood and interstitial fluid that have become trapped in the minimal vasculature of the teat. By applying gentle periodic pressure, fluids are forced upward toward the teat sinus and udder, where more developed systemic vasculature will restore circulation.

Massage was selected over other congestion relief methods because of simple implementation into existing milking machines. The final prototype requires few additional components and integration into the standard teat cup design is easy. There is no additional hassle provided by separate devices and no significant time added to the twice daily milking routine. In order to achieve postmilking treatment farmers are only required to flip a switch on the pulsator, directing airflow valves from positive to negative pressure.

Prototype Testing:

One way to quantify congestion relief is to measure a change in teat wall thickness. An increase in muscle wall thickness indicates the collection of blood and interstitial fluids due to high vacuum force during milking. To evaluate the effectiveness of postmilking positive pressure massage, we used ultrasound take images of each teat quarter premilking, postmilking, and postmassage. These images were used to measure the teat wall thickness at each stage, see Fig. 15.

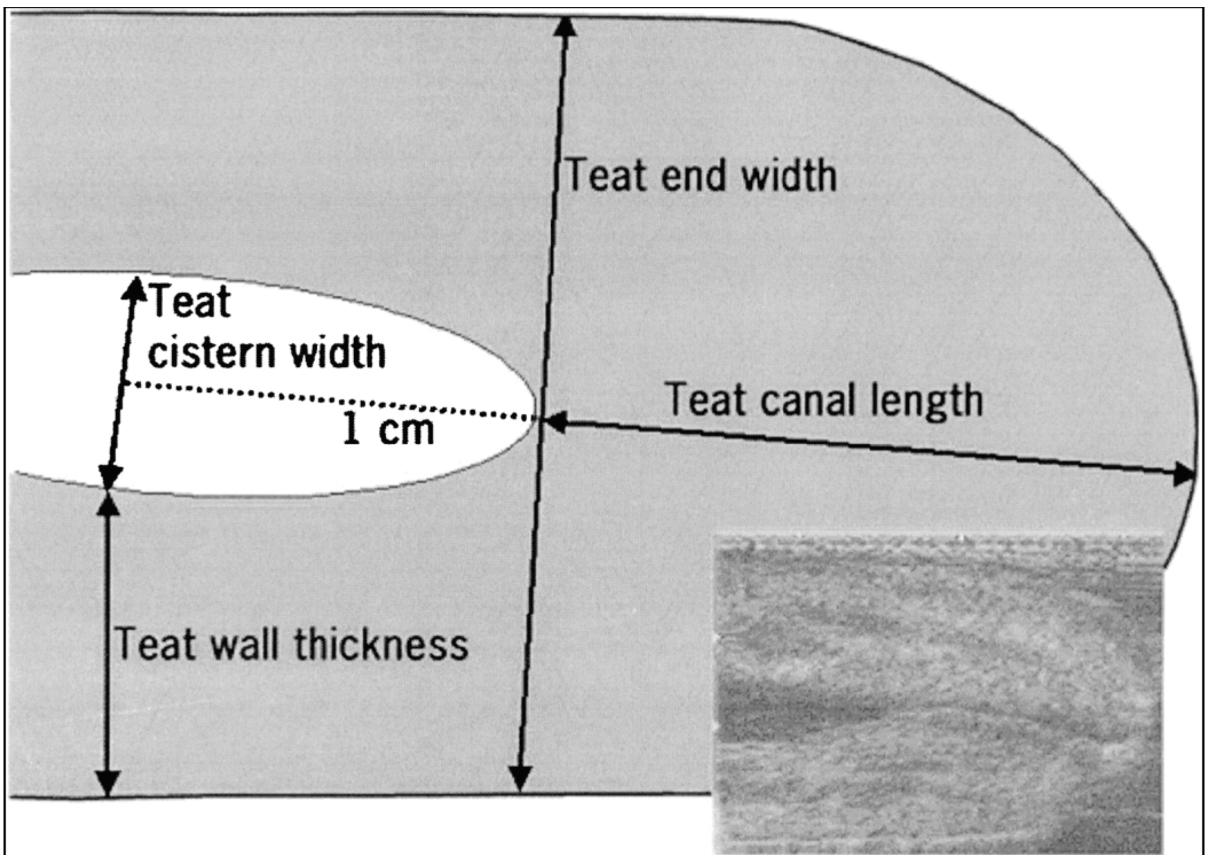


Figure 14: Measurement of teat wall thickness from ultrasound images [5]

Figure 15: Sample ultrasound image

Because our sample size was limited to one cow, the right front and rear teats were given a 90 s massage, while the left front and rear teats served as a control. Fig. 16 and Fig. 17 summarize the results of our testing.

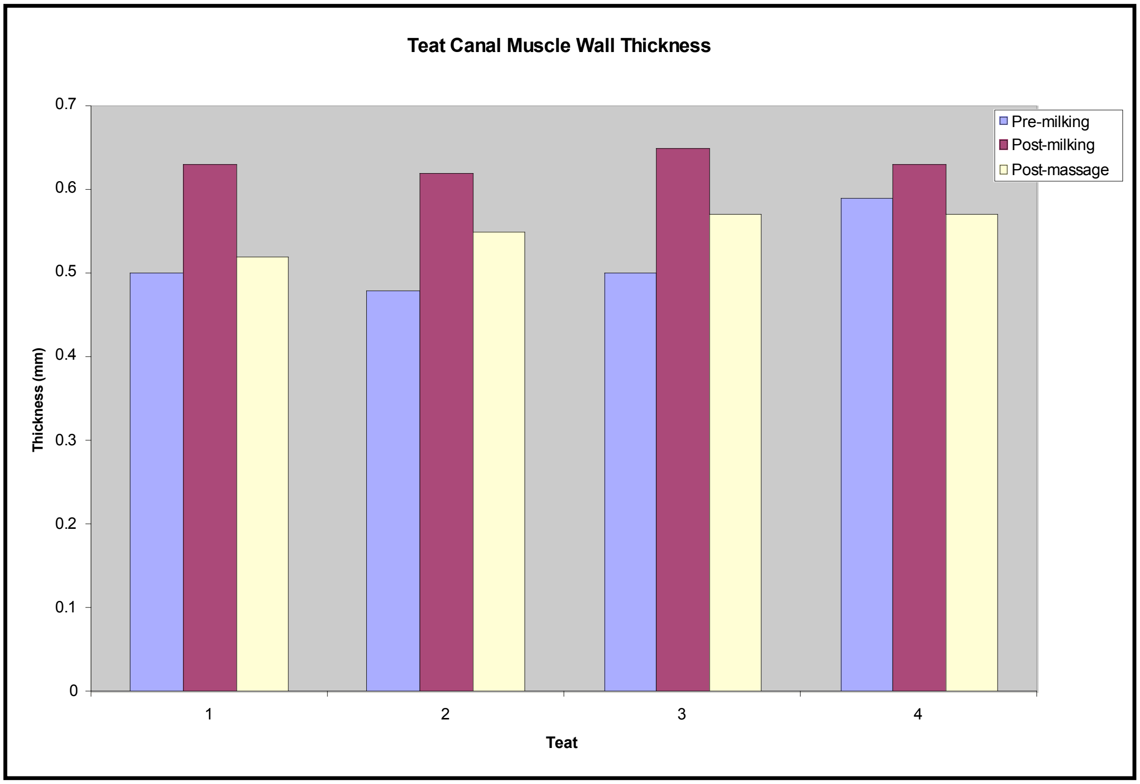


Figure 16: Teat canal wall thickness

Teat	Pre-milking thickness (cm)	Post-milking thickness (cm)	Post-massage thickness (cm)	Percent Reduction (%)
1 Right Front	0.5	0.63	0.52	17.5
2 Left Front	0.48	0.62	0.55	11.3
3 Right Rear	0.5	0.65	0.57	12.3
4 Left Rear	0.59	0.63	0.57	9.5

Figure 17: Teat canal wall thickness

The results from the above table and graph show that congestion was relieved faster with the postmilking massage when compared to no postmilking treatment. This indicates that our device may be helpful in relieving congestion after milking. In order to achieve statistically significant results, more testing is required. Also, increasing the degree of positive pressure and the length of the massage may produce more definite data signifying improved congestion relief.

Future Work:

Now that it is indicated that our positive pressure massage device may reduce postmilking tissue congestion, it is necessary to optimize the temporal and pressure schemes. Optimization of the postmilking massage will involve the variation of pressure levels along with the rate of application to the teat. We will test these different conditions and measure the congestion relief by ultrasound until we find the optimal massage conditions.

Once we have successfully optimized the conditions required for an optimal massage, we will begin looking into ways to incorporate this device into the current milking parlor layout. The implementation of our device will involve the development of a technique for maintaining attachment to the cow, as we currently hold it on manually. Also, a way to efficiently incorporate our device into the current milking parlor layout is needed.

Many ideas have been proposed as solutions for keeping the device attached to the cow, however the most feasible solution is that which uses a small vacuum pressure in the inside of the teat cup liner. Although this solution will take away from the desired congestion relief its benefits far outweigh such disadvantages.

As for efficiently incorporating the device into the layout of the milking parlor, only a few additions would be necessary. Because the piping is already available and our device incorporates many components already in the milking parlor, we simply need to add a valves and tubing along with a positive pressure source.

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Appendix:

Product Design Specification:

TISSUE CONGESTION RELIEF PRODUCT DESIGN SPECIFICATION

Emily Andrews, Tony Schuler, Tyler Vovos, Chelsea Wanta, Steve Welch
October 24, 2007

Function: The current design of automated milking machines relies on a strong vacuum force to extract milk from the sinus udder. As a side effect, blood and interstitial fluids collect in the teat causing tissue congestion and at times, chronic edema. Tissue congestion in cows is not only uncomfortable, but can also lead to canal constriction causing reduced milking speed, bacterial infection, and hyperkeratinization. The newly designed milking machine attachment must extract milk at a comparable rate while simultaneously providing compression of the teat to better reduce tissue congestion.

Client requirements:
- Comparable milking rates
- Measurably reduce congestion

Design requirements:
- Machine and process must be sterile

• Weight must not exceed 2.3 kg total
• No chemicals may leach into milk
• Simple, repetitive technology must be intuitive and convenient for dairy farmers
• An addition to existing machines is ideal to minimize cost
• Must be comfortable for cow

1. Physical and Operational Characteristics

a. *Performance requirements*: The milking process is a manual process in which the claw and teat cups will be placed on each cow by hand. The milking machine will be used on a daily basis; each cow is milked at a minimum of twice a day, however, the machine will be used on different cows during the day. The number of cows each machine is responsible for milking varies with herd size. The inner and outer liners of the teat cups are under constant pressure from the outside; the machine varies between atmospheric and vacuum pressure. The vacuum pressure applied by the machine must remain constant throughout the entire milking process. The milking process takes approximately 4 to 5 min.

b. *Safety*: The device must be sanitized between uses due to its use on different cows. Warnings for proper use and/or instructions should be applied in order to reduce device malfunction, human accidents, and cow discomfort.

c. *Accuracy and Reliability*: Precision is necessary between alternating pressures. When alternating between vacuum and atmospheric pressure, the levels must remain nearly the same between cycles; vacuum pressure must remain between 32 and 40 kPa.

Constant pressure must be maintained throughout the entire milking process, approximately 4 to 5 min, and in each of the 4 teat cups. Low teat-end vacuum can result in liner slips and unit fall-offs. Constant and accurate pressure ensures and efficient and short milking period, as well as minimizes cow discomfort.

d. *Life in Service*: Milking unit used at least twice a day per cow (herd size can vary widely from farm to farm). The inner liner should last for approximately 1,200 milkings; the outer liner will last far longer.

e. *Shelf Life*: The attachment should be stored in a barn, away from weather conditions. The liner of the attachment may need to be replaced after it has shown considerable wear and no longer holds the teat properly. The other parts of the attachment should be durable, and should not need replacement unless they break.

f. *Operating Environment*: The device will be used inside of a milking parlor. It may be subjected to cold and humid temperatures, depending on location and weather. It will also be exposed to dirt and dust from the parlor and should be cleaned regularly.

g. *Ergonomics*: The vacuum of the milking attachment should be between 32 and 42 kPa. The device should not use a vacuum that exceeds 42 kPa because this could cause severe tissue congestion in the cow's teat. The pulsation rate should be 55 to 60 cycles/min and the pulsator on: off ratio should be in the range of 60:40 to 55:60.

h. *Size*: The size of the device should be similar to conventional milking attachments used today (between 0.9 and 1.8 kg) If the device is too heavy, a stronger vacuum would need to be used to keep it on the cow, and this could cause tissue congestion and well as add extra strain on the teat. There should be adequate space in the milking parlor to store the device.

i. *Weight*: Existing teat cups weight approximately 0.9 to 1.8 kg each. No minimum weight requirement exists. However, finding suitable materials to reduce this weight would be difficult and unnecessary. Granted, a lighter cup could use less suction to stay on the teat, but farmers will not sacrifice milking speed for lower suction.

Running along the same lines, a heavier teat cup would require more suction to stay on, which would cause more tissue congestion.

j. *Materials*: The liner is made of a given flexible plastic with varying shape and thickness. Different liners vary in specifications, but they all share the same principle of being flexible and shapely to accommodate the form of the teat. The shell is made of hard metal, which allows atmospheric pressure to enter between the interior of the shell and the exterior of the liner.
The materials used must maintain the milk quality and flow rate while avoiding skin or tissue reactions (allergic or infectious) on the teat.

k. *Aesthetics*, *Appearance, and* Finish: The machine need not look "pretty" or satisfy any aesthetic requirements whatsoever. Its shape, however, should allow for ease of grip by the farmer so he or she may slip the cups on as quickly and efficiently as possible.

2. Production Characteristics

a. *Quantity*: One prototype needed.

b. *Target Product Cost*: Budget is undetermined at this point, however, due to the number of milking machines per farm, cost cannot be extremely high.

3. Miscellaneous

a. *Standards and Specifications*: Our new device must meet and/or exceed the standards of the current milking machine.

b. *Customer*: The user will be dairy farmers who would like to minimize tissue congestion and discomfort in cows while maintaining a high milking rate. Concepts and ideas may be taken from this project and used in human patients to relieve tissue congestion.

c. *Patient-related concerns*: At this time, no concerns beyond those of the standard and widely accepted milking machine have been posed. Our project introduces no new cow/user related concerns.

d. *Competition*: There have been many attempts to improve the standard milking machine, yet none have prevailed to date. Many ideas fix one problem, but leave other issues unaddressed or even worsen them.

Experimental Design:

THE EFFECTS OF POST-MILKING POSITIVE PRESSURE MASSAGE ON TISSUE CONGESTION RELIEF

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November 16, 2007

Introduction and Purpose

The purpose of this experiment is to quantitatively measure the tissue congestion relief provided by a post milking massage. Our group will record the amount of the tissue congestion in each teat tested through the use of skin fold calipers and ultrasound imaging. Using different pressures for each test we will determine what pressure (if any) provide the optimum tissue congestion relief.

Theory

The use of a massage to relieve congestion in the teat of a cow is a technique that is already implemented in current milking machines during the milking process. Unfortunately, this massage increased the amount of time required for milking and is accompanied by the unfavorable vacuum pressure used to pull milk from the cow's teat. Rather than manipulate the milking cycle or pressure fluctuations during, we will focus on relieving tissue congestion postmilking, using a very low pressure vacuum to keep the teat cup attached to the cow, and a positive pressure massage. However, prior to implementing this new technique we must determine the value of such a positive pressure massage.

Each experiment (using a different pressure) will be performed on a sample of five cows. Each cow will have two teats that receive a postmilking positive pressure massage and two teats that will not. Skin fold calipers will be used to measure the thickness of the teat end (i.e. the relative amount of congestion in the teat) before milking, immediately after milking, immediately after the massage, and at one and two hours after the massage. We will first try a positive pressure massage of about 14 kPa above the touch point (approximately 30 kPa of positive pressure total). We will then adjust the pressure up or down depending on our results. Once we find a pressure that significantly relieves tissue congestion after milking, we will use ultrasound to get a more accurate reading of the teat canal wall thickness.

Experimental Procedure

<u>Experiment 1</u> (*n*=5 cows)

- Measure teat end thickness using skin fold calipers prior to milking
- Perform regular milking routine
- Record milking time and volume of milk extracted
- Measure teat end thickness immediately after milking
- Apply 14 kPa positive pressure massage to 2 teats
- Measure teat end thickness of all teats again immediately after massage
- Measure teat end thickness at one and two hours after the massage

<u>Experiment 2</u> (*n*=5 cows)

- Measure teat end thickness using skin fold calipers prior to milking
- Perform regular milking routine
- Record milking time and volume of milk extracted
- Measure teat end thickness immediately after milking
- Apply positive pressure massage to 2 teats
- Measure teat end thickness of all 4 teats again immediately after massage
- Measure teat end thickness at one and two hours after the massage

<u>Experiment 3</u> (*n*=5 cows)

- Measure teat end thickness using skin fold calipers prior to milking
- Perform regular milking routine
- Record milking time and volume of milk extracted
- Measure teat end thickness immediately after milking
- Apply positive pressure massage to 2 teats
- Measure teat end thickness of all teats again immediately after massage
- Measure teat end thickness at one and two hours after the massage

<u>Experiment 4</u> (*n*=5 cows)

- Perform ultrasound premilking and record thickness of teat canal wall
- Perform regular milking routine
- Record milking time and volume
- Perform ultrasound postmilking and record thickness of teat canal wall
- Perform postmilking massage on 2 teats utilizing the optimal kPa of positive pressure found
- Perform ultrasound postmassage and record thickness of teat canal wall
- Perform ultrasound and record thickness of teat canal wall one and two hours after the massage

Results

Experiment 1

Positive Pressure (kPa):14
Time (min):
Volume:

	Cow 1				Cow 2				Cow 3				Cow 4				Cow 5			
Teat	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Pre-milking thickness (mm)																				
Post-milking thickness (mm)																				
Post-massage thickness (mm)																				
1 h post massage thickness (mm)																				
2 h post-massage thickness (mm)																				

<u>Experiment 2</u>

Positive Pressure (kPa):
Time (min):
Volume:

	Cow 1				Cow 2				Cow 3				Cow 4				Cow 5			
Teat	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Pre-milking thickness (mm)																				
Post-milking thickness (mm)																				
Post-massage thickness (mm)																				
1 h post massage thickness (mm)																				
2 h post-massage thickness (mm)																				

<u>Experiment 3</u>

Positive Pressure (kPa):
Time (min):
Volume:

	Cow 1				Cow 2				Cow 3				Cow 4				Cow 5			
Teat	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Pre-milking thickness (mm)																				
Post-milking thickness (mm)																				
Post-massage thickness (mm)																				
1 h post massage thickness (mm)																				
2 h post-massage thickness (mm)																				

Experiment 4

Positive Pressure (kPa):
Time (min):
Volume:

	Cow 1				Cow 2				Cow 3				Cow 4				Cow 5			
Teat	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Pre-milking thickness (mm)																				
Post-milking thickness (mm)																				
Post-massage thickness (mm)																				
1hr post massage thickness (mm)																				
2hr post-massage thickness (mm)																				