Energy Benefits of Pulsation Stop Control on Dairy Farms

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ABSTRACT

Pulsators are an essential part of modern dairy milking systems. They provide the necessary teat massage needed to milk a cow in a safe, efficient, and healthy manner. Normally, pulsators operate continuously during milking. Energy savings are possible if the pulsators are shut off during the time when the milking unit is detached from the cow. This action, called pulsation stop control (PSC), can be performed by either automatic detacher systems or pulsation monitoring systems, depending on the manufacturer.

Automatic detacher systems with PSC provide labor savings, better udder health, and improved equipment lifetimes. Pulsation monitoring systems with PSC provide these benefits and in addition monitor individual pulsators to insure for proper operation and monitor and record overall parlor performance.

Traditionally, these benefits have been the primary reasons for use of a these systems, with energy savings being an ancillary benefit. This report documents the energy savings observed on six southern California dairies due to PSC. Energy is saved in two ways: reduction of the air flow rate of the vacuum system, and reduction of the power drawn by the individual pulsator solenoids.

Introduction and Background

General Dairy Farm Milking Information

On modern dairy farms, milking is performed by a milking unit or milking assembly (see Figure 1) which consists of a milking claw, four rubber liners, and metal shells or housings surrounding each liner. The claw is a collection point for the milk and is connected to a milk tube through which vacuum is applied to the claw and milk flows down to the collection header. The liner is the part that is attached to each teat and extracts the milk from the cow.

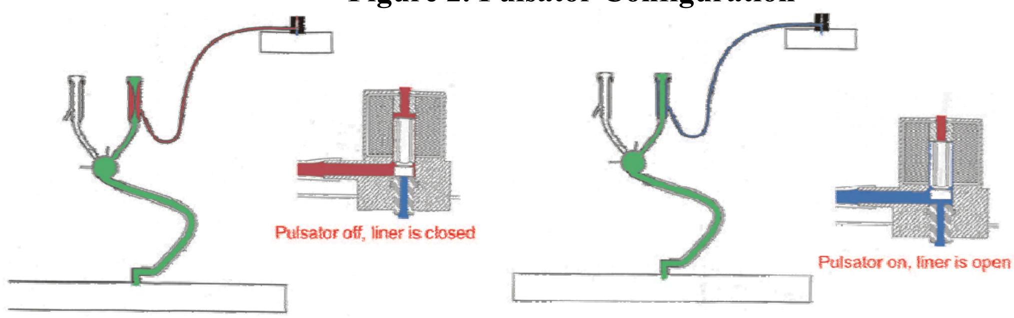
Figure 1. Milking Unit or Milking Assembly

Source: BECO Dairy Automation

Milk cannot simply be sucked from the cow by applying vacuum to the liner/claw assembly. Instead, a massaging action is required, where the teat is periodically exposed to vacuum and then allowed to rest. This is where the shell comes in; it is connected to a different vacuum line. The essential massaging action is accomplished by periodically applying vacuum, and then atmospheric pressure, to the shell space between the shell and liner. When vacuum is applied to the shell space, the liner relaxes from the teat (vacuum pressure being the same on both sides of liner), the vacuum from the claw is exposed to the teat, and milk flows. When the shell is vented (atmospheric pressure is applied), the liner collapses, the teat is no longer under vacuum and it is allowed to rest in preparation for the next massaging cycle.

The device that controls the vacuum to the shells is called a pulsator. Typically, this is a three port electric solenoid valve, connected to a vacuum source, atmospheric air, and tubes going to the milking unit. The solenoid receives its signal from a controller that sets the amount of time the shell space is exposed to vacuum and the amount of time it is vented. (See Figure 2.) These times can be set to optimize milking performance.

Figure 2. Pulsator Configuration



Source: BECO Dairy Automation

Each milking unit is actually connected to three vacuum hoses: one connecting the claw to the milk line which carries away the milk, and two connecting pulsators to shells/liners (one to two of four shells and one to the other two shells). The reason there are two sets of shells is because the front two teats are connected to one pulsator and the back two teats are connected to another. The pulsation action is synchronized so that when the front teats are being milked the back ones are resting and visa versa.

Vacuum System

A milking barn will typically have one vacuum system with one to two vacuum pumps. One pump is used during milking and other used as a spare. The vacuum system provides vacuum to both the milk hoses and the pulsator hoses. The air flow through the milk hoses is fairly constant during milking, as there is typically a small vent in each claw that allows a small amount of air to enter, promoting good milk flow to the milk line. When the milking unit is not connected to the cow, the liner's connection hose drapes down the sides of the claw and is pinched off, reducing the amount of airflow entering the liner's open end and passing through the claw and going into the vacuum system. However, as the liners are attached or detached from the cow, there is a momentary surge of air into the vacuum system. Similarly, if a liner is poorly attached or if the cow kicks off the milking unit, there can also be a large inflow of air.

This fluctuation in airflow would cause a corresponding fluctuation in vacuum pressure on all other milking units connected to the system, unless a pressure control system is installed. Steady vacuum pressure is critical to safe, efficient milking: too high a vacuum can injure the teat and or udder, and too low a pressure can allow backflow of milk into the teat causing mastitis. Typical milking pressure is 13.5 "Hg of vacuum with pressure fluctuations limited to no more then plus or minus 0.6 "Hg.

In the past, this pressure fluctuation problem was addressed by using a fixed speed vacuum pump sized large enough to handle the worst case maximum air flow rate, along with a vacuum pressure valve with pressure sensor/controller. The valve was installed near the milk receiver tank. During times of low airflow demand by the milking system, the sensor would detect the vacuum pressure becoming too strong and would open the valve and allow a large amount of makeup air to enter the system, maintaining the vacuum pressure at desired levels. When the milking system had high airflow demand, the sensor would sense vacuum pressure becoming too weak and would throttle back the valve, allowing less makeup air into the system, and keeping vacuum pressure steady.

This control system was effective, but was very energy intensive, because the vacuum pump was always operating at maximum airflow and speed even though the milking system only actually required that airflow for a very small percentage of the milking time.

In the last decade (since 1997), an alternative solution has entered widespread use. Instead of running the vacuum pump at constant speed, a Variable Speed Drive (VSD) with feedback pressure is used to control its speed to maintain proper vacuum pressure. This allows the pump to turn slowly for much of the milking time, and speed up only when there is a momentary period of high airflow demand as described above.

VSDs have come down in price and have improved their reliability significantly in recent years. The most common type of VSD controls the motor speed by adjusting the frequency of the electric signal to the motor, and as such, is sometimes called a Variable Frequency Drive (VFD). The energy savings achievable by this approach are significant, often exceeding 50%. In addition, the drives decrease the noise levels of the system, decrease the wear and thus increase the useful life of the motor.

Modern Milking vacuum systems are sized according to a specification of the American Society of Agricultural and Biological Engineers (ASAE 1996). Equation 1 shows the recommended basic pump capacity required for modern, well designed milking systems.

Equation 1. Recommended Milk Vacuum Pump Capacity

$C = (35 + 3n)$ ft3/min
Where:
C = Vacuum Pump volumetric flow rate in ft3/min or cfm
n = Number of milking units

This represents the flow rate required when the pump is operating at full speed. The VSD will control the actual speed of the pump as necessary.

Pulsation Stop Control Information

Each time the pulsator goes through its cycle, it evacuates and then vents the volume contained in between the shell and the liner, and in the hose between the pulsator and the shell. While this flow is intermittent and fairly small for each milking unit, when multiplied by many milking units it represents a significant fraction of the total airflow into the vacuum system.

When the milking unit is not attached to the cow, the pulsators are normally still in operation even though they are not serving any useful purpose. This accounts for a significant percentage of time both prior to milking (cow entry into stall, udder cleaning, massage, milk squirt inspection, and wipe-off/health check) and after milking (teat dip and exit from the stall). In batch style parlors with two sides (parallel or herringbone) there is also significant wait time while some cows wait to be milked in one side or wait for other cows to finish milking on the other side. On carousel style parlors, where the cow enters a moving circle at the one o'clock position and then rides around to the twelve o'clock unloading position, there is wait time while the stall returns to the unload position. In all, the milking unit can sit idle for well over half the overall milking time.

The focus of this study is to document the potential electrical energy savings associated with stopping the pulsator operation during all times that the milking unit is not attached to the cow. This feature will be referred to as Pulsator Stop Control (PSC).

Using PSC has the potential to save energy and demand in two electrical consuming systems. The first system is the power supply for the pulsation units which convert the 120 voltage to a lower 24 volts to energize the solenoid inside each pulsation unit. When fewer pulsation units are being used, less energy will be required at the pulsator power supply. The second system is the vacuum pump system. When fewer pulsation units are being used, less atmospheric air enters the vacuum piping system, less air needs to be pumped out by the vacuum pump and the pump motor will used less energy. In order to have the vacuum pump energy savings, the parlor must have a VSD with pressure feedback control on its vacuum pump; otherwise the reduction in airflow would not actually result in any reduction in energy usage with a fixed speed vacuum pump.

In addition, there must be a way to detect that the milking unit is not attached to the cow. Fortunately, many modern dairies already have a milk flow sensor as part of an automatic detacher system. This system shuts off the claw vacuum and pulls the milking unit away from under the cow when it detects that milk flow has fallen below a minimum value. Without automatic detachers, an operator must watch the many milking units, decide when milk flow has ended, and manually remove the milking unit. So besides saving labor, detachers eliminate over-milking which can be harmful to the cow. Majority of Southern California dairies have automatic detachers.

Finally, there must be a way to stop individual pulsators. Again, there are fortunately systems available, called pulsation monitoring systems and other separate controls that can be installed on existing pulsation controls systems to accomplish this.

A simple prediction of vacuum pump energy savings can be made by reviewing Equation 1 and ASAE (American Society of Agricultural Engineers) S518S in more detail. The 3 ft^3/min per milking unit is actually made up of the following:

- 1 ft^3/min per milking unit for incremental component of effective vacuum reserve
- Pulsator consumption of 1 ft^3/min per milking unit.

- Claw air admission of 0.35 ft^3/min per milking unit.
- All multiplied by a factor of 1.2 to cover system leakage, regulation loss, frictional losses, and pump wear.

So, it is reasonable to expect that the pulsators alone should account for about 1.2 x (1 ft^3/min) or 1.2 ft^3/min per milking unit. As an example, for a 50 milking unit dairy, the recommended capacity would be 35 + 3(50) = 185 ft^3/min, with the pulsators accounting for about 50(1.2 ft^3/min) = 60 ft^3/min, or about 32% of the total. If it is further assumed that the pulsators are turned off for 50% of the milking time, then a reasonable estimate of the vacuum pump savings would be 50% of 32% or about 16% savings.

In addition to the vacuum pump savings, there are also expected savings associated with actuating the pulsator solenoid by the low voltage power supply. Without specific information on the solenoids, it is difficult to estimate this savings up front, other than to say that it should be directly proportional to the amount of time the pulsators are shut off, or about 50% savings.

Dairy Farm Market Information

As mentioned in the Abstract, the PSC feature can be provided by either an automatic detacher system, or a pulsation monitoring system. An automatic detacher system has a sensor that detects when milk flow has dropped below a preset level, a valve that shuts off the vacuum to the milk line and the pulsators, an arm that physically withdraws the unit from underneath the cow, and all associated alarms, switches, and control circuitry. The main benefits of an automatic detacher system with PSC are:

- Labor savings, since the parlor worker does not need to watch milk flow and manually remove the milking unit
- Improved udder health, due to not under or over milking the cow
- Extended liner and pulsator life, due to fewer operating cycles

Pulsation monitoring systems are higher level, supervisory sensing and control systems. They work in conjunction with automatic detachers. In addition to the benefits listed above, they also provide:

- Continuous pulsation monitoring, ensuring that the pulsator fully expands and contracts the liner/shell quickly and remains in the milk and rest phases for the specified times each cycle. If pulsators aren't operating properly, cows could be harmed, milk times could increase, and overall milk yield could decrease. Without an on-site continuous monitoring system, pulsators are checked only periodically (usually monthly); these checks can often miss intermittent pulsation problems for weeks.
- They continually monitor and record milking times and sequences, which can help to spot health problems or to understand and optimize overall milking operations

The PSC option is now available from the major dairy equipment manufacturers (BECO, Delaval, Westfalia-Surge, and Boumatic.) No manufacturers currently offer the PSC feature as a stand alone option, however some suppliers have expressed interest in offering it as a retrofit to in-place automatic detacher systems. It is expected that such a retrofit would provide energy savings equivalent to what has been documented in this study.

Economic Payback Analysis

The cost of installing a system that provides the PSC feature varies significantly by manufacturer. It can cost as little as $250 per stall to upgrade from a basic detacher without PSC to a more advanced system with PSC. To install a pulsation monitoring system with pulsation stop control option can cost between $500 and $1500 per stall depending on how sophisticated the system is. The energy cost savings provided by PSC are on the order of $18 per stall, so the simple payback based on energy savings alone is over 30 years at best. Clearly this is not economically justifiable. However, as stated earlier, farmers usually install PSC-capable equipment for reasons other than energy savings.

All current manufacturers set up their systems so that, if the PSC feature is available, it is enabled. However, in some cases, farmers choose to have the feature disabled. This may be due to the farmer simply being conservative and not wanting to change the way they have always operated. In other cases, the system is set up so that if the detacher circuit board fails, the pulsators will still work and cows can be milked, albeit with manual detachment. Doing so provides some measure of reliability, but prevents the use of PSC. To date, farmers have not had reliable energy savings data on which to base these decisions.

So, increasing the use of PSC, and achieving the associated energy savings, may in some cases be a matter of proper education and field verification, to give the farmer some confidence that using PSC will not have any adverse effects on his operation.

Finally, if suppliers offer the PSC feature as a retrofit option, the cost may be low enough to be economically justifiable based solely on energy savings and potential associated utility incentives.

Useful Life

Automatic detacher systems and pulsation monitoring systems are new enough to the market that no data exist on their useful life. However these systems, as well as simplified PSC-only systems, are or would be made up of fairly common electric components, so a useful life in excess of 10 years would be expected.

Test Methodology

Six dairy farms were selected for the study between December 2007 and December 2008, having the following key requirements:

- A milking system with the ability to easily enable or disable the PSC feature.
- A vacuum pump system using variable speed drive (VSD) with pressure feedback controls. (So that reduced vacuum airflow would actually result in energy savings.)

It so happens that the only systems on the market that allow the PSC feature to be easily enabled or disabled were pulsation monitoring systems from a single manufacturer. The automatic detacher systems could be configured to either enable or disable the PSC feature, however to do so required a technician to make a hardware change to each individual pulsator.

This was time-consuming and prone to error. We felt it was unreasonable to expect farmers, who were volunteering to help with the study, to accept the risk that their milking operations would be adversely affected. As a result, all farms in the study had pulsation monitoring systems from a single manufacturer. While we would have preferred to include several manufacturers in the study, we feel the results are unlikely to differ significantly from one manufacturer to the next.

We attempted to include a range of parlor sizes. However, since pulsation monitoring systems are more likely to be installed on larger farms, the evaluation included mostly farms toward the larger side of the size range, even for Southern California, with the exception of Dairy 6. We wanted to include all common parlor types (parallel, herringbone, and carousel). Table 1 lists the farms included in the study along with information about each facility.

Table 1. Dairy Farm Information

Farm Name	# of Vacuum Pumps	Vacuum Pump HP	# of Pulsat. Power Loggers	# of Milking Units	Milkings per day	Average Time per Milking (hours)
Dairy 1	1	20	1	50	2	7.75
Dairy 2	1	20	1	46	2	9.58
Dairy 3	2 (note 1)	20	2	70	2	9.62
Dairy 4	2 (note 2)	20	2	64	2	10.41
Dairy 5	2 (note 1)	20	2	80	2	9.27
Dairy 6	2 (note 1)	7.5	1	12	2	4

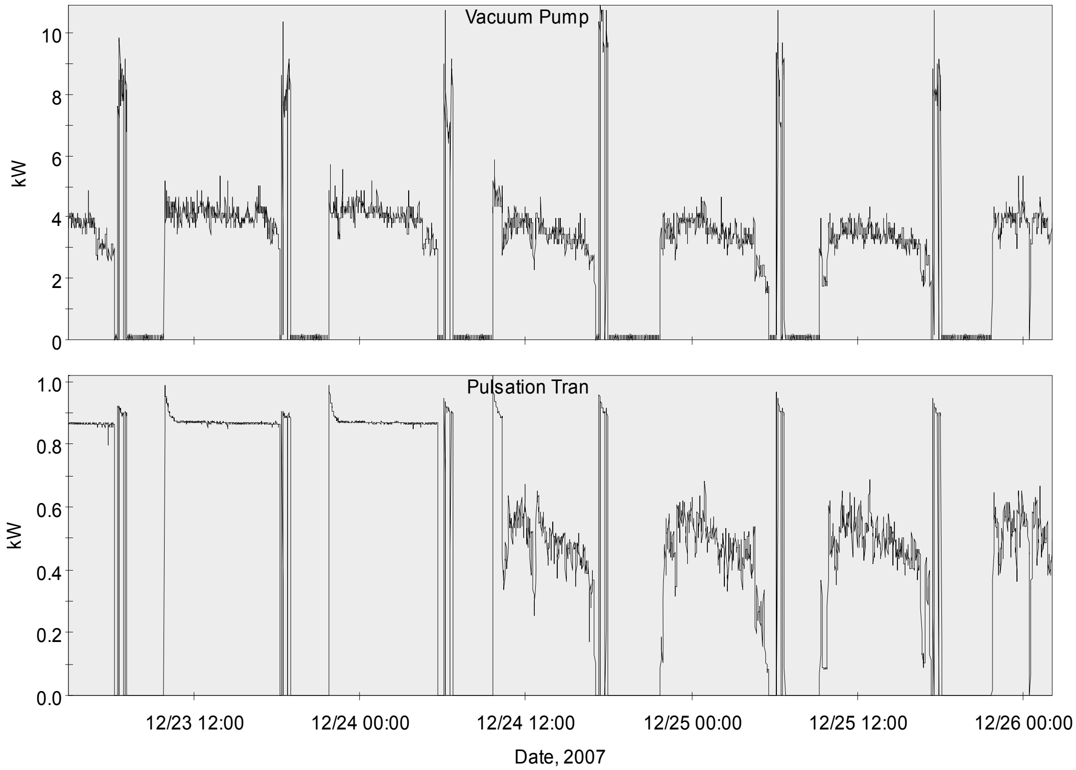
Note 1 – Only one vacuum pump operated during the milking period.
Note 2 – Alternating vacuum pumps used for milking, but only one is used at a time during milking period.

Dataloggers were installed at each farm to monitor the energy use for both the vacuum pump motor and the pulsator power supplies. Each farm was monitored for at least one week in the “PCS-on” mode and one week in the “PSC-off” mode.

Results

Figure 1 shows a typical datalogger trace for both the vacuum pump and the pulsator power supply (transformer). On all farms there is always a very clear change on the pulsator power supply trace when the PSC feature is switched. In this particular example, the switch is from PSC-disabled to PSC-enabled and it occurs around 9:30 am on 12/24. The vacuum pump difference is not as distinct, but is clearly evident.

Figure 1. Typical Datalogger Traces for Vacuum Pump and Pulsator Power Supply (Transformer)



Data from the dataloggers were averaged for each farm for each mode ("PSC-enabled" and "PSC-disabled") and the results are summarized in Table 2. Power use during the washup operation was not included, since typically all pulsators are on constantly, and the vacuum pump runs at full speed during washup.

Table 2. Energy Savings Summary

Farm Name	% savings of Vacuum System	% Savings of Puls. System	Savings (kW/MU)	Avg. Milk Time (hours)	Milkings /Day	Energy Savings (kWh/year /MU)	Cost Savings @ $0.10/kWh ($/year/ MU)
Dairy 1	21.3%	47.7%	0.0252	7.90	2	145	$14.53
Dairy 2	21.8%	54.2%	0.0293	9.57	2	205	$20.49
Dairy 3	4.2%	42.3%	0.0139	9.61	2	98	$9.78
Dairy 4	16.6%	40.8%	0.0225	10.41	2	171	$17.07
Dairy 5	18.0%	45.7%	0.0279	9.27	2	189	$18.88
Dairy 6	5.9%	60.3%	0.0176	3.79	2	49	$4.86
					Overall Average:	143	$14.27
					Overall Average without Dairies 3 & 6:	177	$17.74

Overall, the results show savings in the expected range. Vacuum pump savings ranged from 4.2% to 21.8%, versus an estimate of 16% as discussed earlier. Pulsator savings ranged from 40.8% to 60.3%, versus an expected value of 50%.

As expected, the energy savings due to the vacuum accounted for the larger portion of the savings, contributing about 60% while the pulsator savings contributed about 40%. There were two farms, Dairies 3 and 6 that did not seem to realize the expected vacuum pump savings. We believe there are two separate reasons for this.

Firstly, Dairy 3 has an unusual type of control system for the vacuum pump VSD. This system continues to use an old vacuum control valve as an integral part of the control system. The other farms simply have a pressure sensor with a feedback controller that sends a signal directly to the VSD. The expectation is that on Dairy 3, the old vacuum pressure control valve is letting in significant bypass air. Without even considering the effects of PSC, this farm looks unusual in that its initial power use (kW/milking unit) is significantly higher the other farms. So, the farm starts out higher than normal, and doesn't save very much when PSC is added. We believe both these observations can be explained by the nature of the VSD control system.

Secondly, Dairy 6 has a vacuum pump VSD control system similar to the other farms, and its initial power use (kW/milking unit) is also very similar to the other farms. In this case, we expect that with the PSC feature enabled, the vacuum pump is simply running so far below its normal capacity that it is unable to operate efficiently. For vacuum pumps, power is roughly a linear function of speed at constant pressure, so this would correspond to a speed signal out of the VSD of 16% of 60 Hz or 10 Hz, which may be approaching the practical lower limit of the VSD and is likely in a region where motor efficiency significantly degrades. Without further investigating the detailed layout and control of this dairy's vacuum system, we think this explanation is consistent with the observations.

Conclusions

- Pulsation Stop Control (PSC) provides measurable energy savings.
- Energy Savings are only one of many benefits associated with systems that provide the PSC feature.
- Energy Savings were close to predicted values for both the vacuum pump and the pulsation power supply.
- Unusually low vacuum pump energy savings were observed on two dairies. The likely reasons for these observations were identified.
- For currently available systems, installation of the PSC option is not economically justified if based solely on energy savings.

References

[ASAE] American Society of Agricultural and Biological Engineers. 1996, *S518.2 Milking Machine Installations – Construction and Performance*. St Joseph, Minn.: American Society of Agricultural and Biological Engineers