Paper Number: 033013
An ASAE Meeting Presentation

Dry Tests of Vacuum Stability in Milking Machines with Conventional Regulators and Adjustable Speed Vacuum Pump Controllers

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Written for presentation at the
2003 ASAE Annual International Meeting
Sponsored by ASAE
Riviera Hotel and Convention Center
Las Vegas, Nevada, USA
27- 30 July 2003

Abstract. *A survey of vacuum control, noise levels and energy savings was performed on 15 farms in Lombardia, Italy comparing conventional vacuum regulation systems with variable speed drive (VSD) control systems on each milking machine. The data showed that if VSD controllers are set up properly they are able to meet or exceed the vacuum stability of conventional regulators. The reduction in noise levels achieved by VSD control systems averaged about 12 dB with up to 24 dB reductions in some locations. The energy saved by using VSD controllers was considerable, averaging 56%, with up to 87% savings observed on larger systems. VSD controllers also reduce the starting current of large electric motors, which may be a significant advantage when operated on some rural power distribution systems.*

Keywords. Milking Machines, Control Systems, Energy Conservation, Noise Levels

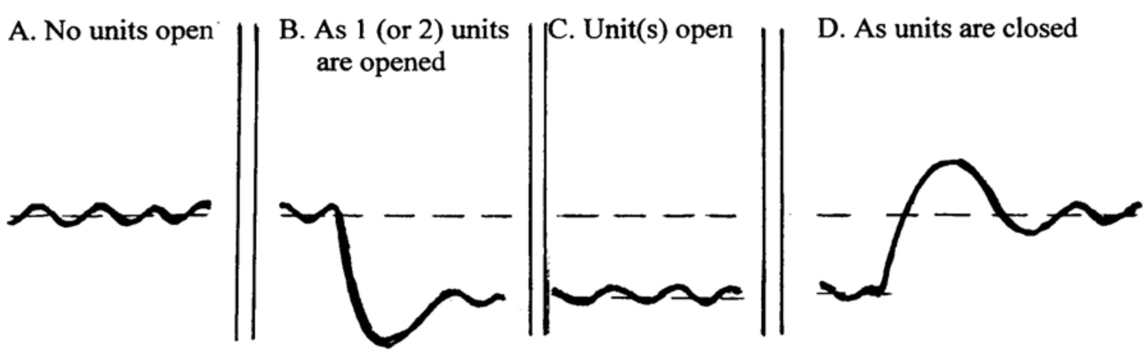
Introduction and Methods

New vacuum control technology for milking machines using variable speed drives (VSD) for vacuum pump motors has been introduced into the commercial market during the past decade. These controllers are now being installed in significant numbers in Europe and the USA. This paper presents the results of a field study comparing performance of VSD controlled milking systems to those controlled with conventional regulators. Vacuum stability, response time, energy use and noise levels were studied on fifteen farms in Italy.

Conventional vacuum regulation relies on varying the air admission to the milking machine as the air used by the machine changes to maintain a stable vacuum level in the milking machine. The vacuum pump runs at a constant RPM with the amount of air removed by the vacuum pump remaining relatively constant (there is some variation in air moved depending on the vacuum at the pump inlet). The conventional regulator responds to changes in vacuum at its' sensing point. If the vacuum is above the intended set point the regulator admits more air into the milking machine. If the vacuum is below the intended set point the regulator admits less air into the milking machine.

Air uses that are more-or-less steady include: pulsation, air vents in milking clusters, and air leaks in pipes. Air is admitted intermittently when milking units are attached to and detached from cows' teats. The volume of air admitted during these operations depends on the skill and care used by the operators of the milking machine. Large unplanned air admissions also occur during liner slips and milking unit falloff.

Figure 1. Measurements of vacuum drop, undershoot and overshoot during a unit falloff test.



Working vacuum	= Average of A.
Vacuum drop	= (Average of A) – (Average of C)
Under-shoot	= (Average of C) – (Minimum of B)
Over-shoot	= (Maximum of D) – (Average of A)
Response time	= Time elapsed from vacuum drop in B until the vacuum "C" is stabilized.

Note: When making these measurements, ensure that:

- The vacuum recorder is set to a sampling period of about 10-15 seconds for each segment;
- The milking unit(s) opened during the test are located downstream of the recorder connection inlet to minimize the local effects of high airflow past the connection point

Rather than changing the extra air admitted to the milking machine, the VSD controllers match the air removed by the vacuum pump to the air used by the milking machine. The VSD system responds to system vacuum just as a conventional regulator, but if the vacuum exceeds the intended set point the controller reduces the speed of the vacuum pump motor so that less air is removed from the system. If the vacuum is below the intended set point the controller increases the speed of the vacuum pump motor so that more air is removed from the system. VSD controlled systems reduce the energy used by the milking system because the vacuum pump must only remove the air that has been admitted to the system rather than the maximum expected instantaneous air admission at all times.

This survey was performed on 15 farms in Lombardia, Italy to examine the performance of VSD vacuum control systems. Performance was recorded using the conventional vacuum regulator as well as the VSD control system on each milking machine. Four different brands of VSD controllers were tested.

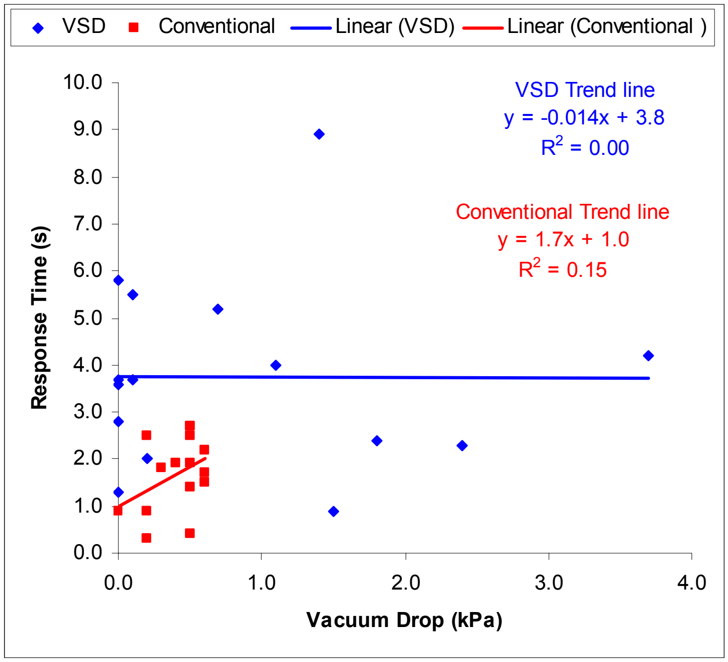
Vacuum Drop and Response Time

A dry "falloff" test was performed on all milking machines with both regulation systems using the methods specified in ISO 6690. The fall-off test is an indication of the adequacy of the effective reserve airflow of a milking machine. One milking unit is opened to allow the maximum air admission to the milking system. The vacuum drop, time required for the system to reach this stabilized vacuum level, and undershoot were recorded. The milking unit was then closed to eliminate the extra air admission and the overshoot was recorded. Details of these measurements are illustrated in Figure1 and the results of these tests are presented in Table I.

Table I. Results of falloff tests (numbers in red exceed ISO recommendations)

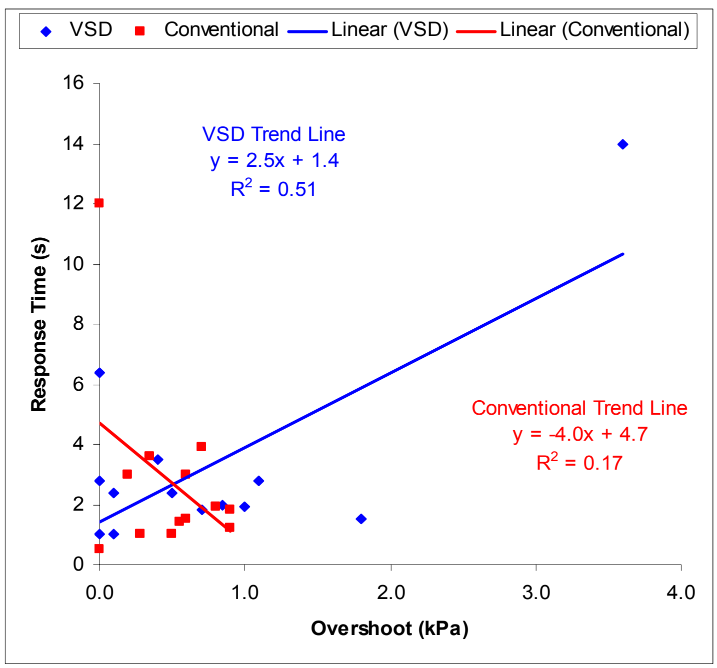
VSD type	Farm	Vacuum Drop (kPa)			Response Time (s)		
		Regulator	VSD	Difference	Regulator	VSD	Difference
A	1	0.6	0.0	-0.6	2.2	2.8	0.6
	2	0.5	0.7	0.2	2.7	5.2	2.5
	3	0.2	1.8	1.6	2.5	2.4	-0.1
	4	0.6	2.4	1.8	1.7	2.3	0.6
B	5	0.4	1.4	1.0	1.9	8.9	7.0
	6	0.5	1.5	1.0	1.9	0.9	-1.0
	7	0.5	3.7	3.2	2.7	4.2	1.5
	8	0.2	1.1	0.9	0.3	4.0	3.7
C	9	0.5	0.2	-0.3	0.4	2.0	1.6
	10	0.6	0.1	-0.5	1.5	3.7	2.2
	11	0.5	0.0	-0.5	2.5	5.8	3.3
	12	0.0	0.0	0.0	0.9	1.3	0.4
D	13	0.2	0.1	-0.1	0.9	5.5	4.6
	14	0.3	0.0	-0.3	1.8	3.7	1.9
	15	0.5	0.0	-0.5	1.4	3.6	2.2
Average		0.41	0.87	0.46	1.69	3.75	**2.07**
Std dev.		0.18	1.11	1.10	0.79	2.04	2.02

The vacuum drop is primarily a function of the frictional losses between the receiver and the vacuum sensing point under the airflow conditions of the falloff test. There was no statistically significant difference between the vacuum drop generated by a unit falloff on systems controlled by conventional regulators versus VSD control systems when all systems were compared using a paired T-Test. Seven of the fifteen systems had a smaller vacuum drop when controlled by the VSD and eight of the fifteen systems had a larger vacuum drop when controlled by the VSD. ISO standards specify performance criteria for the vacuum drop in the receiver of 2 kPa or less from the vacuum set point for a unit falloff test. Two of the fifteen VSD controlled systems tested failed this test.



A paired T-test showed a significant increase in the response times for the VSD controlled systems when compared to conventional regulation. It should be noted however, that two of the fifteen VSD controlled systems had a faster response time and three additional VSD controlled systems had 0.6 s or less increase in response time than when controlled by a conventional regulator.

The response time was regressed against vacuum drop, overshoot and undershoot for both conventional and VSD controlled systems. There was no correlation between the amount of vacuum drop and the response time of the VSD controlled systems and a slight upward trend for the conventionally controlled systems.



The response times of the VSD controlled systems tended to increase with the amount of overshoot while the conventionally controlled systems tended to move in the opposite direction. However, both trends were highly influenced by an “outlier”. When these extreme points were removed the trends were not apparent.

Adjusting a variable speed motor controller is much more difficult than setting a conventional vacuum regulator. Conventional regulators have fixed sensitivity and response rates, while these parameters are selectable for VSD controllers. In order for the VSD to function optimally its sensitivity and response rate must be matched to the system. VSD controllers use proportional integral control logic. This is a complicated strategy to adjust the response to return to the target value as quickly as possible without overshooting the target.

Noise Levels

The noise level was measured in the pump room near the vacuum pump, in the milk room and in the milking parlor on ten of the farms and for each type of regulator. The results of these measurements are presented in Table II.

Table II. Noise levels for conventional regulator and VSD vacuum controller.

Farm	Pump Room Regulator	Pump Room VSD	Pump Room Reduction	Milk Room Regulator	Milk Room VSD	Milk Room Reduction	Parlor Regulator	Parlor VSD	Parlor Reduction
1	90	84	6	76	66	10	74	74	0
2	92	76	16	79	72	7	76	69	7
3	88	77	11	88	77	11	74	65	9
5	99	82	17	86	71	15	75	69	6
6	96	73	23	85	61	24	69	53	16
8	91	82	9	66	62	4	70	67	3
9	91	89	2	82	73	9	67	66	1
10	89	78	11	76	56	20	64	62	2
13	90	75	15	86	69	17	74	71	3
14	90	81	9	80	68	12	75	66	9
Average	92	80	12	80	68	13	72	66	6
Std.	3.4	4.8	6.0	6.6	6.3	6.1	4.0	5.7	4.9

Noise levels were, on average, 12 dB lower in the pump room, 13 dB lower in the milk room, and 6 dB lower in the parlor with VSD than with conventional regulation systems. The main sources of noise are the vacuum pump itself and the air admitted to the regulator. The difference in noise levels for each location will therefore depend on the location of the regulator and the vacuum pump as well as the overall reduction in vacuum pump speed achieved by the use of the VSD controller. The maximum noise reductions achieved were 23 dB in the pump room, 24 dB in the milk room, and 16 dB in the parlor.

Energy Use

The energy use on five of the farms was recorded with both regulation systems. The results of these measurements are presented in Tables III and IV.

Table III. Characteristics of farms used for energy study.

Farm	Milking Cows	Milking Units	Milkings Per day	Vacuum Pump Capacity l/min	L/min* unit	KW	kW / unit	Work Hours per day
1	86	16	3	2 x 1800	112.5	2 x 3	0.19	5.0
3	161	10	2	2000	200	5.5	0.55	9.3
6	146	20	2	2 x 3200	160	2 x 8	0.40	6.8

Farm	Milking Cows	Milking Units	Milkings Per day	Vacuum Pump Capacity l/min	L/min* unit	KW	kW / unit	Work Hours per day
10	68	10	2	1350	135	4	0.40	3.9
14	175	24	2	3000	125	9	0.38	7.0

Table IV. Energy used with different vacuum control systems.

Farm	Regulator		VSD		Energy Savings	
	Average Power (kW)	Total energy kWh/day	Average Power KW	Total energy kWh/day	kWh/day	%
1	2.9	14.2	1.7	8.5	5.7	40.3
3	3.3	30.6	1.6	14.3	16.3	53.3
6	4.6	31.1	1.2	8.1	23.0	73.9
10	2.2	8.6	1.6	6.5	2.1	24.2
14	3.3	22.8	0.5	3.0	19.8	86.8
Average Energy Savings 56%						

Energy savings averaged 56% on the five farms tested with the maximum energy savings of 87% and the minimum 24%. The percentage of energy saved tended to be greater on larger milking systems.

Conclusion

VSD controllers can meet or exceed the vacuum stability of conventional regulators if they are installed and adjusted optimally. However, installation and adjustment of VSD systems does require greater skill on the part of the installer than conventional regulation systems.

The reduction in noise levels achieved by VSD control systems is substantial. Noise reduction is achieved by reducing the noise generated by the vacuum pump (by running at lower speed) as well as eliminating the considerable noise generated by the air admission of conventional regulators. This noise reduction makes for a much better work environment for both cows and humans.

The energy saved by using VSD controllers is considerable, averaging 56%, with up to 87% savings observed on some systems. VSD controllers also reduce the starting current of large electric motors, which may be a significant advantage when operated on some rural power distribution systems.

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