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A method for assessing liner performance during the peak milk flow period

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ABSTRACT

The objective of this study was to develop a method to quantify the milking conditions under which circulatory impairment of teat tissues occurs during the peak flow period of milking. A secondary objective was to quantify the effect of the same milking conditions on milk flow rate during the peak flow rate period of milking. Additionally, the observed milk flow rate was a necessary input to the calculation of canal area, our quantitative measure of circulatory impairment. A central composite experimental design was used with 5 levels of each of 2 explanatory variables (system vacuum and pulsator ratio), creating 9 treatments including the center point. Ten liners, representing a wide range of liner compression (as indicated by overpressure), were assessed, with treatments applied using a novel quarter-milking device. Eight cows (32 cow-quarters) were used across 10 separate evening milkings, with quarter being the experimental unit. The 9 treatments, with the exception of a repeated center point, were randomly applied to all quarters within each individual milking. Analysis was confined to the peak milk flow period. Milk flow rate (MFR) and teat canal cross sectional area (CA) were normalized by dividing individual MFR, or CA, values by their within-quarter average value across all treatments. A multiple explanatory variable regression model was developed for normalized MFR and normalized CA. The methods presented in this paper provided sufficient precision to estimate the effects of vacuum (both at teat-end and in the liner mouthpiece), pulsation, and liner compression on CA, as an indicator of teat-end congestion, during the peak flow period of milking. Liner compression (as indicated by overpressure), teat-end vacuum, vacuum in the liner mouthpiece, milk-phase time, and their interactions are all important predictors of MFR and teat-end congestion during the peak milk flow period of milking. Increasing teat-end vacuum and milk-phase time increases MFR and reduces CA (indicative of increased teat-end congestion). Increasing vacuum in the liner mouthpiece also acts to reduce CA and MFR. Increasing liner compression reduces the effects of teat-end congestion, resulting in increased MFR and increased CA at high levels of teat-end vacuum and milk-phase time. These results provide a better understanding of the balance between milking speed and milking gentleness.
Key words: liner performance, peak milk flow, vacuum, pulsation, congestion

INTRODUCTION

One practical limitation to increasing milking speed by increasing milking vacuum or pulsation ratio is the resulting stresses on teat tissues, associated discomfort for cows, and potential increase in mastitis risk. Whereas the vacuum and pulsation conditions that affect milking speed have been widely studied, liner properties and milking conditions under which teat tissue congestion occurs have not been well quantified.

Increasing milking vacuum was shown by Williams et al. (1981) to increase milk flow rate (**MFR**) while also increasing teat-end congestion and decreasing teat canal cross section area. In a trial assessing 3 levels of milking system operating vacuum (**Vs**), increasing vacuum from 30 to 50 kPa resulted in an increase in teat-end thickness as measured with a cutimeter (Hamann and Mein, 1988). Mein and Reinemann (2007) reported that increasing Vs from 40 to 50 kPa produced a 20% change in MFR, with the dominant effects occur during the peak flow period of milking. Williams and Mein (1986) and Ambord and Bruckmaier (2010) found a significant increase in peak milk flow rate (**PMF**) when Vs was automatically increased with increasing MFR. O'Callaghan and Gleeson (2004) concluded that teat-end vacuum during the b-phase of pulsation is positively correlated with MFR and negatively correlated with total milking time.

Hamann and Mein (1996) reported that pulsation settings that increased MFR (shorter d-phase and longer

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b-phase) also increased postmilking teat-end thickness. Those authors also noted that the effect of liner was at least as large as the effects of pulsation, but only tested 2 liners. Gleeson et al. (2004) found that increasing pulsator ratio from 0.60 to 0.67 shortened total milking time, although MFR was not specifically measured. Mein et al. (2004) reported that MFR reached a maximum for pulsator ratios between 0.60 and 0.70 and that a reduction in MFR seen at pulsator ratio of 0.80 is probably due to insufficient time for congestion to be relieved during the d-phase of pulsation.

Liner compression, as defined by Mein et al. (2003), can also have an influence on MFR. Overpressure (**OP**) is a biologically relevant indicator of liner compression (Leonardi et al., 2015). Williams and Mein (1986) controlled liner compression through changes in pulsation chamber pressure and noted a decrease in MFR with decreased liner compression. Bade et al. (2009) found that increasing vacuum, b-phase duration, and liner compression increased PMF at the udder level, with the effects of liner compression most pronounced at high milking vacuum levels.

Teat-end congestion (or the accumulation of fluids in teat-end tissues) can influence MFR by reducing teat-canal cross sectional area (Upton et al., 2016b). This is based on the assumption that the outer skin layers of the teat-end are nearly fully distended at vacuum levels above about 40 kPa (Williams et al., 1981) and the resulting swelling of the soft inner tissues of the teat-end cause the canal to become restricted. Understanding how milking machine settings influence teat congestion is also important with regard to IMI risk. Hamann et al. (1993) postulated that the efficiency of local and systemic defense mechanisms might be impaired due to congestion after milking at higher Vs. Congestion effects might impair immunological function in 2 ways: first, through an increased time for teat canal closure after cluster removal and, second, via direct effects on immunological defense mechanisms (Paulrud, 2005). An association between higher MFR and the risk of new IMI has also been reported (Grindal and Hillerton, 1991). The objective of our study was to develop a method to quantify the conditions under which circulatory impairment of teat tissues occurs during the peak flow period of milking. A secondary objective was to quantify the effect of the same milking conditions on MFR during the peak flow rate period of milking, with both objectives providing guidance to users on the physiological limitations to increasing milking speed.

MATERIALS AND METHODS

The experiment was carried out at the University of Wisconsin-Madison Dairy Cattle Center and was

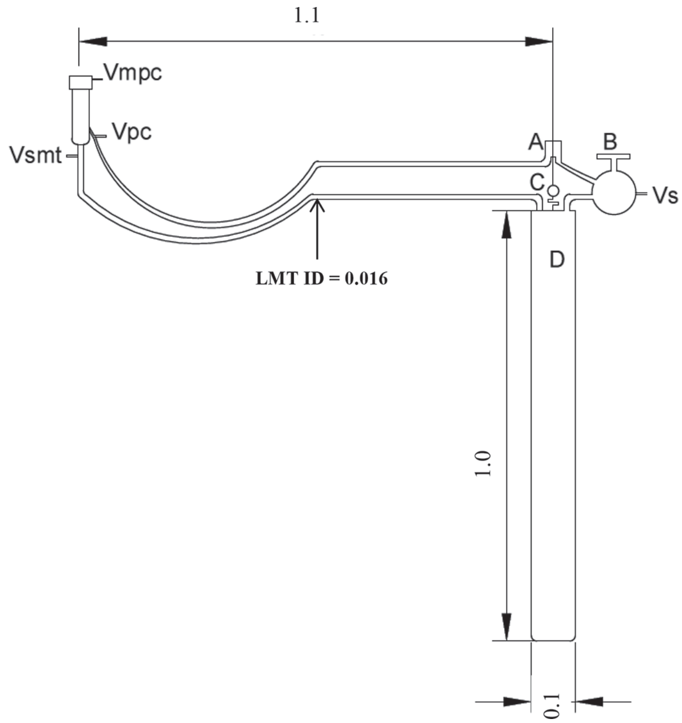

Figure 1. Diagram of 1 teat-cup arrangement of the quarter milking analysis device. A = pulsator; B = vacuum regulator; C = weigh cell; D = milk collection tube; Vs = milking system operating vacuum; Vmpc = mouthpiece chamber vacuum measurement point; Vpc = pulsation chamber vacuum; Vsmt = short milk tube vacuum; LMT = long milk tube. Dimensions in meters.

approved under institutional animal care and use committee animal use protocol A005167. Milking was done using the quarter-milking device described by Upton et al. (2016a) and illustrated in Figure 1. Vacuum levels in the pulsation chamber, short milk tubes (**Vsmt**), mouthpiece chambers (**Vmpc**), and cumulative milk weight for each quarter were recorded at a sampling rate of 1,000 Hz.

We used an inscribed central composite experimental design (Box and Wilson, 1951), with 5 levels of both pulsator ratio (from 0.50 to 0.70) and Vs (from 37 to 50 kPa) as the explanatory variables (Figure 2) and MFR and cross sectional area of the teat canal (**CA**) as the response variables. The pulsation rate was adjusted to maintain a rest (c+d) phase of 400 ms so that the main effect of changing pulsation ratio was to change the milk (a+b) phase, which ranged from 400 to 933 ms. One of 10 different liners was used for all of the 8 experimental cows at each afternoon milking session. The physical characteristics of the liners are summarized in Table 1. Overpressure was measured for each liner according to the method described in Leonardi et al. (2015).

All cows were prepared for milking with a teat disinfectant and wiped with a clean cloth before attachment