Perfection of methods and testing means of milking systems

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Regarding to requirements of international standards the comparative analysis of interaction of milking units with teats of animal udder allows to receive time parameter diagrams which describes operation of milking units in dynamics. Besides phases of pulsation cycle for them are as follows: the beginning and the end of milk letdown moments; contact points of liner walls; the beginning and the end of massage of teat by liner; periods of full milk letdown and teat of liner massage; vacuum of balance (if vacuum becomes lower than this level, it will act as „over-pressure“) or effective massing influence of teat on teat tip operates; integrated influence of liner on animal udder teat.

Control of the specified parameters is carried out with help of microprocessor measuring parameter instrument of the milking equipment EXITEST-2.1, supplied with complete set of gauges. The device includes electronic unit with display and printer, removed vacuum pressure gauges, multi-purpose artificial teat-sensor, air flowmeter, external charge device, adapters-fittings and tubes for connection. The device allows controlling vacuum modes of the milking and vacuum systems of the milking equipment in dynamics.

The artificial teat-sensor is equipped with the following: gauge measuring vacuum pressure in teatcup liner; hydrodynamic pressure gauge, perceiving through artificial teat cover of the integrated influence of liner and liner vacuum on teat. It’s also stipulated: transformer controlled a vacuum mode in a mouthpiece chamber, imitation of milk letdown and regulation of penetration depth of artificial teat-sensor in a teatcup.

Key words: Artificial teat sensor, integrated influence on teat, generalized rigidity of liner

Summary
The studies of L.P. Kartashov, S.A.Soloviov, D.I. Reinemann, M.A. Davis, G.A. Mein, K. Muthukumarappan, M.D. Rasmusen [2,3,5], E. Harty, P.M. Grace, E.J.O’ Callaghan, J. Szlachta, K. Aleksander, M.C. Butler, H. Worstorff, E. Bilgery [6] and others are dedicated to improvement of systems and facilities for analysis of interaction between suspended part of milking units with teatcups of particular liners (L) with udder teats of animals. The aim of the above-mentioned studies was to find out the way of impact of teatcup liner both on the very teat as a whole, and on the tip of cow’s teat, as well as on its hyperkeratosis reaction.

Moreover, many researchers supplement the requirements to testing methods of milking systems stated in ISO standard specifications [1].

Analysis of interaction nature of milking units (MU) with animal’s udder teats, processes occurring in a claw, long milk tube MU and milk line and vacuum system of milk installation, as well as taking into account the requirements to milking units testing stated in the standards ISO 5707 and 6690, standards ASAE EP 445 and S 518, results obtained by key researchers [2,3,5,6] and our own researches [4] allow to combine the above-mentioned statements and to present time diagrams of parameters which describes an overall performance of milking units (see fig. 1).

Pulsing vacuum pressure transmitted by pulsator to teatcup pulsation chamber (PC) is shown on fig.1 in form of diagram $P_{v.1}$. Vacuum pressure in liner vacuum (LV) chamber of teatcup (TC) - in form of diagram $P_{v.2}$. Its characteristic sections are vacuum surge in LV while liner opening and milk flow just starting (JS) of a teat and vacuum fall in LV while liner closing and milk flow stopping (StM) of a teat. Shape of curve $P_{v.2}$ significantly depends on parameters of suspending part MU (volume of milk chamber and type of claw, parameters and condition of liner and a short milk tube, form and overall dimensions of an udder teat, milk flow rate intensity, etc.).

Let’s allocate standard breakpoints with help of which we can define phases $a$, $b$, $c$, $d$, sucking times (milking) $t_{milk}$ and massage (rest) $t_{mas}$ on diagram $P_{v.1}$, minus 4 kPa as respects to the upper and lower level in accordance with standard ISO 3918.

Let’s allocate characteristic points on diagram $P_{v.1}$ on the base of research results of Mein G. [2]:
- SM (◊) – start of teat massage by liner and start of teat channel opening;
- StM (●) - end of milk flow rate, due to the teat channel is pinched by line. This moment corresponds to touch point (TP) of liner walls;
- JS (◊) – just start of milk flowing owing to start of teat channel opening while liner disconnecting;
- EM (●) - end of teat massage by liner (at full stop of its non axisymmetric deformation), that corresponds to full opening of the teat channel.
Thus, in contrast to distinguished phases of pulsation cycle \((a, b, c, d)\) according to ISO 3918, we can assume that the following sections of \(P_v\) are characteristic zones and we mark them out as: JS - EM - phase \(a'\); EM - SM - phase \(b'\), which characterizes the process of “clear” milk flow rate with duration \(t_{b'} = t_{w''}\); SM - StM - \(c'\); StM - JS - phase \(d'\), which characterizes the process of influence of compressive liner load on teats, usually designated in science literature as over-pressure (OP) with duration \(t_{d'} = t_{mas'}\).

Then milking time duration (time of total milk flow rate) is equal \(t_{m'} = t_{a'} + t_{b'} + t_{c'}\) and time of massage (period of full massage) - \(t''_{mas} = t_{c'} + t_{d'} + t_{a'}\) (according to, approximately \(t''_{m} : t''_{mas} \approx 65:35\) and \(t''_{m} : t''_{mas} \approx 50:50\)).

The periods of total milk flow rate and massage marked out in the diagram are overlapped in phases \(a'\) and \(c'\).

Curve RV passes through characteristic points EM and SM. The curve describes residual vacuum for massage (vacuum necessary for liner closure). Vacuum pressure in the milk chamber of claw \(P_{v,c'}\) measured at the moment of sensor connection is 38-42 or 44-48 kPa, depending on type MU.

After vacuum has reached the level called equilibrium vacuum \(P_{v,eq}\) [2], in the pulsation chamber of a teatcup, JS - milk flow just starts and StM - milk flow stops. Compressive force (force of liner influence on teats) is balanced by “fanning force” on vacuum level \(P_{v,eq}\), as a result of higher vacuum level \(P_{v,2}\) in LV, within closed liner. It was shown, that the optimal value of \(P_{v,eq}\) is 8-12 kPa [2].

Below this vacuum level the liner carries out one of the major functions - the teat effects on a tip (massages it) while liner bending around it is being compressed with force, defined by so-called over-pressure (OP), or « compressive load »[2].

Efficiency of milking from an udder (without dropsied, stagnation and hyperkeratosis – which is damage of teat tips), and, therefore, health of cows depends on efficiency of OP influence.

There is a problem of control of level of integrated interaction of teats with a teatcup while researching and testing parameters MU. To solve this problem we are developing a device for measuring parameters of milking equipment with an artificial teat-sensor (ATS), schematically shown on fig. 2 while interacting with TC. In case of similar developments [2,3], the following problem was set: estimation of complex influence of teatcups of suspended part MU on a whole teat body in dynamic, from base, mouthpiece, central part to tip, as well as from insertion depth into TC. We think it will allow to estimate character of impact of massing procedure of teatcups liners both on a whole teat, and on its tip in details.
ATS is made in form of an average cow’s udder teat and is an elastic membrane 1 filled with a special liquid 2. There is channel 3 along ATS axis. It is for milk simulator run and it is for damp testing. An elastic tube 4 for simulation of milk flow rate dynamics is inserted in the lower end of the membrane in the channel 3. Membrane 1 is attached to body 5 in its upper part with help of sleeve 6 and washers 7. Device 8 for regulation of teat elasticity is mounted into sleeve 6. Sensitive element 9 of the sensor is mounted in the lower part of the teat. The sensor is intended for recording of vacuum gauge pressure $P_{v.1}$ in the liner vacuum chamber under teat tip. An additional ring 10 is mounted on membrane 1 for better contact between ATS and liner and for improvement of its sensitivity. Vacuum pressure sensor 14 connected to mouthpiece chamber (C.Mth) by channel 15 is built into body 5 of mouthpiece chamber of liner 11 TC 12 (Fig. 2) put on ATS 13 in order to carry out vacuum pressure $P_{v.Mth}$ control.

Integrated dynamic liner impact, teatcup liner vacuum $P_{v.2}$ and suspended part MU on ATS through membrane 1 is registered by the built-in hydrodynamic pressure (PHD) sensor 16 installed in body 5 and is marked out as a characteristic $R_e$.

$R_e$ is an integrated resulting pressure inside of the working hollow of membrane 1 as a result of interaction between ATS and teatcup liner 11 and suspended part of milking unit

$$R_e = f(P_{v.1}; P_{v.2}; P_{v.Mth}; T; H; E; B; L; \delta; \psi; \xi), \text{kPa}$$

where: $T$ - liner tension, N; $H$ - liner hardness, on Shore A; $L_s$ - shell length, mm; $L$ - liner length, mm; $B$ - liner bore, mm; $E$ - modulus of elasticity of liner material, N/m$^2$; $\delta$ - walls thickness of liner, mm; $\psi$ and $\xi$ - coefficients depending on ATS design features and suspended part of MU.

To control ATS insertion depth in a teatcup, ring nozzles 17 are put on teat 13. In order to carry out dynamic (damp) test MU and simulation of milk flow rate, in accordance with requirements of ISO 5707, ATS is equipped with feeding system 18 of milk simulator $Q_{m.i}$.

We made a device for measuring parameters of milking equipment “EXITEST” in 1993 and equipped it with reduced version of ATS [4]. The latest version of microprocessor device EXITEST-2.1 is equipped with sophisticated ATS. It contains two remote vacuum gauges pressure sensors, artificial teat-sensor, gauge –flowmeter of air stream, complete set of tees and nozzle-adapters providing connection to any point of testing milking equipment.

Diagram $R_e$ (fig. 1) was obtained with help of ATS of the above-mentioned device while carrying out control of parameters MU at the same time with measurement of vacuum pressure pulsations. According to results of preliminary researches [4] the inverted diagram $R_e$ corresponds to diagram $P_{v.1}$ with approximately 2 % time delay in terms of phases of pulsation cycle that is a result of inertia of liner motion relative to vacuum oscillations in PC.
Idealizing interaction process (Fig. 1), lets copy characteristic points JS (○), EM (●), SM (□) and StM (●) down from diagram $P_{v.1}$ on diagram $Re(t)$ and obtain points $JS'$ (○), $EM'$ (●), $SM'$ (□) and $StM'$ (●) there. After that we can allocate series of characteristic levels on time diagram $Re(t)$:

Level of points $JS'$ and $StM'$, where $Re(t) = Re.cr$ corresponds to integral impact of suspended part MU at equilibrium vacuum $P_{v.eq}$ on a teatcup teat (i.e. liner and liner vacuum).

Below this level the diagram section (from $Re.eq$ to $Re.max$) characterizes a value range of „compressive load” or an over-pressure occurred while massaging and swaging a teat tip by close liner. The maximum overpressure value is $Re.op = Re.max - Re.eq$. As appears from the above, over-pressure value (compressive load) $Re.op$, defined with help of diagram $Re$ as area of its section $Sop$ which lays below $Re.eq$ within $StM'$-$JS'$ (phase $d'$) can serve as a method of estimation of efficiency of massing impact of liner on a teat tip. Preliminary researches showed that $Sop$ is lower in case of rigid liners, even within allowable phase duration $d > 15\%$. In order to simplify, let’s obtain $Re.eq$ copying point $StM$ of level $P_{v.eq}$ to diagram $Re$. With help of obtained point $StM'$ we draw a horizontal line. Intersections of this line give us point $StM'$ and $JS'$, which define level $Re.eq$. Furthermore we determine area $Sop$ of diagram segment starting from $t'_{3}$ to $t'_{4}$ below level $Re.eq$, between points $StM'$, and $JS'$ according to amplitude $Re.op$.

Efficiency of massing procedure liner on dummy tip can be estimated with help of value $Sop$.

Point EM' corresponds to the moment of completion of teat massage by liner, and the corresponding level can be called critical. It is characterized by minimal force impact, at that pressure in cavity ATS marked out as $Re.cr$. Therefore, reaction $Re$ ATS indicating pressure of full strain of liner is $Re.def = Re.max - Re.cr$. The upper glow iris section $Re$ corresponds to reduction of absolute pressure, in cavity ATS filled with liquid, down to minimum level $Re.o$. The whole pressure range indicating integral impact $Re.i$ on environment ATS and its strain, lays within $Re.o < Re.i < Re.max$ and depends on many parameters. Namely the following: surface condition, rigidity and stress level (owing to a tension) liner, underteat vacuum condition, rigidity of ATS cover, initial pressure of liquid into its cavities, ratio of overall dimensions of ATS and liner and others. Its strict mathematical description is pretty difficult and such a description isn’t cited in the present paper. Integral impact of a teatcup on an udder teat (or ATS) can be estimated with help of amplitude value $Re.i = Re.max - Re.o$.

We have offered a sophisticated ATS version which allows to change rigidity of its elastic part. In case of proper metrology calibration of microprocessor measuring device EXITEST against magnitude $Re$ it is possible to simulate and to estimate impact of TC liner on natural cow’s teats.
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In order to immediately determine impact of liner on teats only, without taking into account impact of underteat vacuum while dry testing, ATS is installed in a teatcup with disconnected collecting channel and other teatcups with removed plugs. As a result we obtain "pure" (without impact of vacuum) value Re.cl, which allows to estimate (generalized) rigidity and tension condition of liner directly in a teatcups. Comparative calibration Re.cl according to standard technique of estimation of liner rigidity at elongation, will allow to receive the corresponding parameter which we called parameter of "generalized rigidity" of liners and which can be estimated with help of ATS—a component of the microprocessor measuring device EXITEST 2.1.

Conclusion

Equipment of microprocessor meter of parameters of milking systems EXITEST-2.1 with proposed ATS, along with other sensors, will provide expansion of its capability. Later on it will allow carrying out the following:

- Registration and estimation of milking system parameters Pv.1; Pv.2; Re, phases of pulsation cycle and vacuum in a milk chamber of claw Pv.c in dynamics;
- Monitoring of vacuum condition Pv.2 directly under teat, during influence of liner on teat's tip;
- Opportunity to record parameters of milking systems while simulating their interaction with teats of different elasticity and lengths;
- Estimation of tension, rigidity, generalized rigidity and extent of wearing off of liners without disassemblies of teatcups with help of Re.cl;
- Tension regulation and selection according to rigidity of liners in teatcups, depending on properties (parameters) of udder and teats of milk cow herds;
- Determination of "over-pressure" value OP, or compressing load of liner on teat tip, according to value of integrated reaction Re.op ATS within the range of phase d ’.
- Determination of integral impact of teatcups on teats R.e.i.

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Figure 1. Characteristic diagrams of pressure and parameters of milking units.
Figure 2. Interaction between artificial teat sensor and teatcup.

