Vadim N.SHOFFA, Victor N. CICERJUKIN[1], Bogdan MIEDZINSKI[2], Xin WANG[3]

Moscow Electric Power Institute Moscow,Russia (1) , Wroclaw University of Technology (2), China Agriculture University, Beijing,China (3)

The Influence of Actuation on Performance of a Mercury Wetted Reed Switch

***Abstract**. Paper presents and discusses results of investigations of performance of mercury wetted reed switches of different structure depending on way of control when actuated by means of an energizing coil. Both switches with change –over as well as make type reeds were considered. On the basis of the investigated results the conclusions on the right reed structure selection and mercury interaction within a contact area are formulated.*

***Streszczenie.** W artykule zaprezentowano i omówiono wyniki badań działania kontaktronów zwilżanych rtęcią, o różnej strukturze, w zależności od sposobu sterowania gdy napędzane są za pomocą cewki. Rozpatrywano zarówno kontaktrony przełączne jak i zwierne. Na podstawie uzyskanych wyników badań sformułowano wnioski odnoście do właściwego doboru konstrukcji kontaktronu jak i wpływu rtęci znajdującej się w obszarze stykowym. (**Wpływ sposobu sterowania na działanie kontaktronu zwilżanego rtęcią**).*

Keywords: mercury wetted reed, switch, energizing coil.
Słowa kluczowe: kontaktron zwilżany rtęcią, łącznik, cewka napędowa.

Introduction

The influence of way of actuation on dynamics of dry reed switches was already considered for practical use [1].In this paper mercury wetted reed switches were taken into account. Their performance is strongly related not only to structure and properties of a magneto-mechanical system of the reed but is also influenced by mercury employed for the contact wetting. Due to the mercury expansion over the blade surfaces being wetted and its relatively slow drainage time by capillary tubes the reed switch dynamics can be significantly disturbed. As a result there are found two mutually dependent processes one of which is due to parameters of the resultant magneto-mechanical system of the reed (particularly its moving parts) and the other-hydrodynamic properties of the mercury itself respectively. They both are strongly related to way of energization of the reed switch what can in turn change the reed switch performance. In the paper performance of the switch with mercury wetted reeds both of a change –over and a make contact set structure was investigated for various way of actuation by means of a coil. On the basis of the investigated results the conclusions on proper selection of a reed structure and the mercury influence on the dynamics of the mercury wetted reed switches in transient under both closure and opening are formulated.

Performance of the change –over reed switch

For investigations available, standard change –over reed samples (KRM-7 type, made in Russia) were selected. To observe the contact set performance under operation a suitable hole inside the driving coil was drilled (it is not indicated in Fig.1).Under quasi-steady state conditions (very slow increase as well as decrease of MMF value (Θ) with time in the coil (5)) the dynamics of a movable blade (4) being separated from non-magnetic contact elements (6) or (8) respectively with corresponding elongation and following breaking of the mercury made bridge was searched by means of an optical microscope. So called critical value of the contact gap (Δ'_{cr}) at steady state opening for which the mercury bridge was effectively broken was found to be around 140μm-170μm.

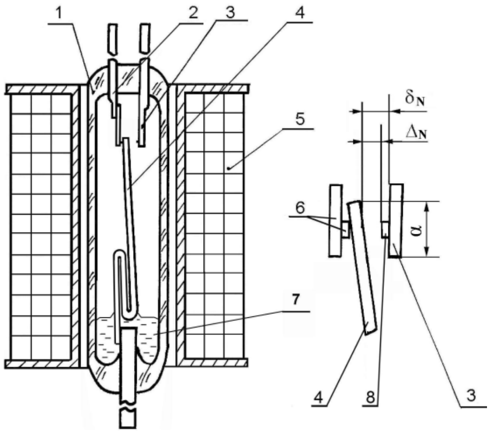


Fig. 1. Mercury wetted change –over reed switch (russian KRM-7 type) glass envelope; 2,3,4-blades; 5-driving coil; 6,8-contact elements; 7-mercury;

While in transient for voltage puls energizations the (Δ_{cr}) was varied and was related both to overdriving coefficient value as well as to the voltage puls duty factor. (Observations were carried out in this case by use of a lighting stroboscope).For different time t_{ny} of the voltage decay duration (at energizing puls with operation time t_{op} fixed to about 20ms) the critical gap can be found from Fig.2. One can see that with the increase in t_{ny}/t_{op} ratio the critical length of the mercury bridge (Δ_{cr}) is higher with compare to this (Δ'_{cr}) under quasi-steady state of operation. While, at the decrease of the break time between following voltage triggering pulses (t_{op}=20ms) the bridge ,in turn, is being broken much faster resulting in smaller (Δ_{cr}) value. It is related to hydrodynamic properties of the mercury both inside the bridge as well as located over the contact areas being wetted. For example under shorter time of the break between driving pulses the mercury amount being delivered to the contact area is at lower intensity with compare to the longer break time. Therefore, the bridge extension before interruption is much smaller. The critical value (Δ_{cr}) of the breaking contact gap for which the mercury bridge is being broken depends also on the blade displacement velocity. Thus, with the increase in overdriving factor K_o from 1 to 1.5 the (Δ'_{cr}) tends to increase independently on the t_{ny} value (see Fig.2).

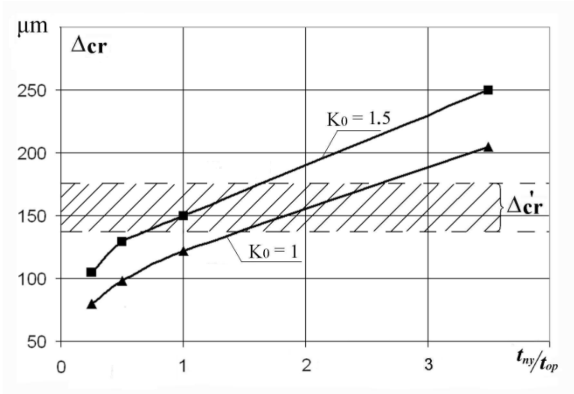
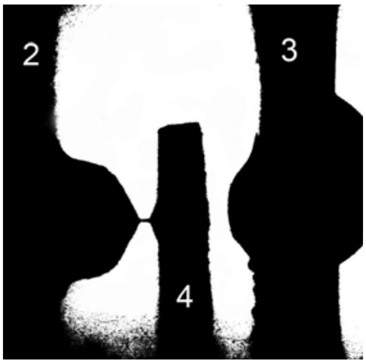
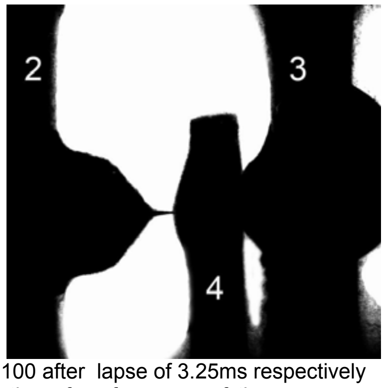


Fig. 2. Variation of critical contact gap value (Δ_{cr}) with time duration t_{ny} of energizing stoppage (driving voltage pulse width t_{op}=20ms) and overdriving factor K_o value(Δ'_{cr}-for quasi steady state operation)

Illustration of the reed performance for different duty factor value of the energizing voltage is given in Fig.3. As one can see under longer break time duration of the energization (t_{ny}/t_{op} =100) the greater amount of mercury being condensed over the break contact area results in extensive elongation of the bridge before interruption (Fig.3b).



a)for t_{ny}/t_{op} =1 after lapse of 2.1ms from beginning of energization



b) for t_{ny}/t_{op} =100 after lapse of 3.25ms respectively

Fig. 3. Illustration of performance of the mercury wetted reed for different t_{ny}/t_{op} ratio (t_{op}=10ms, K_o =1) just before the bridge braking

As a result the change –over reed modifies its performance from the C contact type (break-before-make, Fig.3a) to the D type (make-before-breake, Fig.3b) respectively. Basing on these investigated results one can easy explain effective suppression of a contact bouncing under operation of the mercury wetted reed switch for continuous energizing frequency of 50 Hz when compare to its under spontaneous work. Simply, for the cyclic driving coil energization limited amount of mercury is still maintained at area of open contact elements. Change of contact performance under different way of energization has been confirmed by respective testing, what can be confirmed by records presented for example in Fig.4 and Fig.5.

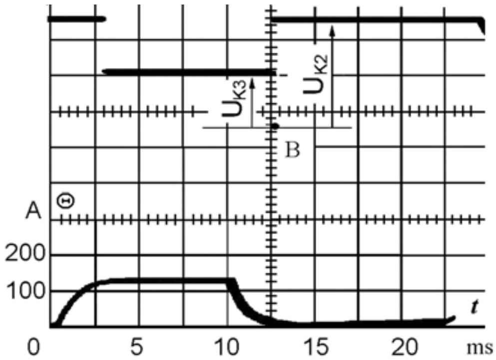


Fig. 4. Oscillograph records of voltage across break (U_{k2}) and make (U_{k3}) contact respectively and variation of energizing MMF (Θ)with time during spontaneous (single)operation of the change-over mercury wetted reed switch

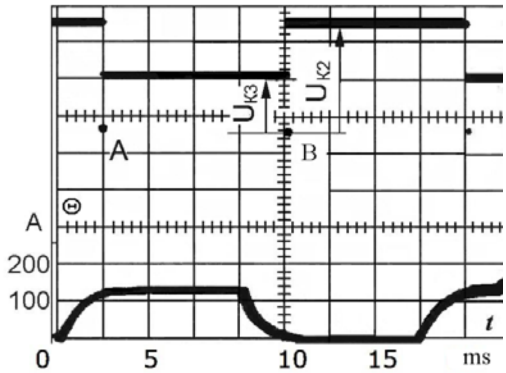


Fig. 5. Oscillograph records for the same mercury wetted reed switch but operated continuously with frequency of 50Hz.

Therefore, for spontaneous operation ($t_{ny}/t_{op} \rightarrow \infty$)the switch performance at closure is "make-before-break" while at releasing-"break-before-make" respectively, what is indicated by appearance of B point in records given in Fig.4. On the contrary at continuous driving with frequency equal to 50Hz its operation was found to be "break-before-make" type what can be revealed by additional point A on the voltage record in Fig.5. Under test the amplitude of first bounce of the make contact was also controlled. It was increased (up to 50um) with the overdriving (K_o = 2) and in a case of increased energizing frequency (at K_o= 1) from 1Hz up to 40Hz as well. However, for the increased overdriving value by about 100% (K_0 =2) the first bounce amplitude did not varied with the frequency. It means, that the mercury wetted reed performance is strongly affected by hydrodynamic properties of the mercury being applied what is disclosed when changing the driving condition. Therefore, to suppress contact bouncing the time duration of the contact under closed state should be selected enough high to allow for providing sufficient amount of mercury located inside the contact area.

It was found to be satisfied when the t_{ny}/t_{op} ratio is equal to 1. Since, the operation MMF value (Θ_0) of the reed switch depends on the energizing frequency therefore, appropriate investigations were carried out under both quasi steady-state and under continuous operation with frequency equal to 1,16,20,25,40 and 60Hz respectively (for duty factor equal to 2).Time constant of the energizing coil (together with the reed inside) was about 4ms.

Contact overlap of the reed was located on a right place inside the coil to get the highest switch sensitivity. To suppress switching overvoltages the coil was shunted by a diode. It was found that the operation MMF value (Θ_0) during slow increase of the energizing quantity with time (quasi steady-state conditions) is higher with compare to this under impulse driving with frequency up to about 25 Hz. It results from the fact that the movable blade (4 in Fig.1) "passes over" the contact gap at smaller MMF value under continuous energizing [3]. However, this relationship is not directly proportional within the range of frequency variation from 1Hz up to 40Hz.The switch sensitivity is thus increased at such frequency at which beginning of the driving puls coincides with the movable blade motion (4 in Fig.1) towards the stationary blade (3 in Fig.1) during its free vibrations. It is decreased under the movable blade withdrawing. This effect is more evident for frequency higher than 20Hz since,the time duration of the break between following pulses of energization is not sufficient to "calm down" the movable blade. If the frequency was over 40Hz, the reed switch was not able to operate at small MMF value. In this case the overdriving factor was needed to be even over 5.

Investigations of mercury wetted make type reed switches

Mercury wetted make type reed switch designed was predicted to conduct heavy load however, without any electrical switching activity. It means that it will be loaded only after the contact making performance is completed. The reed has to be also unloaded before it starts to be released. Therefore, its dynamics in transient under both closure and opening was analyzed for lack of electrical load through the contact.

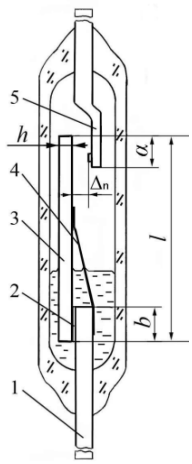


Fig. 6. Mercury wetted make reed switch with nonmagnetic pad 1-pumping tube,2-nonmagnetic (electroconducting) pad, 3-movable blade, 4- return spring, 5-stationary blade. (l=21mm, h=0.6mm, α =2.2mm, b=1.4mm, Δ_n =2mm, Θ =400A)

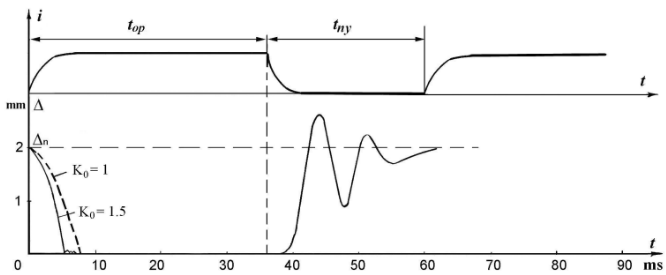


Fig. 7. Current(i) in driving coil and displacement (t) of the movable blade in time under closure and following releasing.

First its physical model (as shown in Fig.6) was assembled for testing [4].Its performance under closure and following opening when energized with frequency of 16.6Hz at duty factor equal to 1.65 is presented for example in Fig.7.(Amplitude of the movable blade vibrations was estimated with accuracy of about 15%) For 50% overdriving (K_o =1.5) total operation time was about 7ms while, this to the first contact closure -5.2ms respectively (release time was around 2ms).However, the contact bouncing was found under closure. Its duration was about 2ms while, the first bounce (lasting 1.8ms) coincides with moment of breaking of the mercury made bridge between contacts.

When overdriving was withdrawn (K_o =1) the resultant bouncing time was found to be reduced by about 50% as well the bouncing magnitude. However, time to the first contact closure increased almost 1.5 times (to 8ms) and the mercury bridge was not observed to be broken at that time. Under releasing, independently on the overdriving (K_o) value the blade vibrations were relatively high (see Fig.7).It is not considered as a good since it increases hazard of electrical breakdown of the contact gap in transient. In a case when holdfast of the movable blade to nonmagnetic pad (2 in Fig.6) was increased the blade chattering tended to decrease successfully. Much better effects were obtained for another reed structure presented in Fig.8.

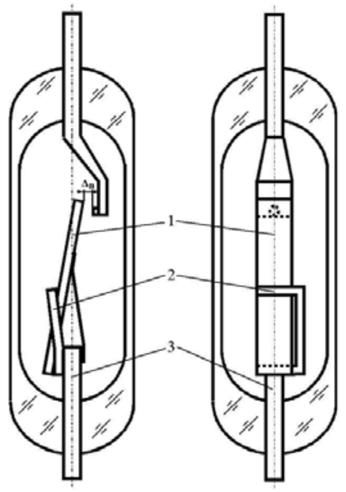


Fig. 8. Mercury wetted make reed structure with a movement limiter(support) of the movable blade, (1-movable blade,2-nonmagnetic,electroconducting,movement limiter (support),3-filling pipe,)

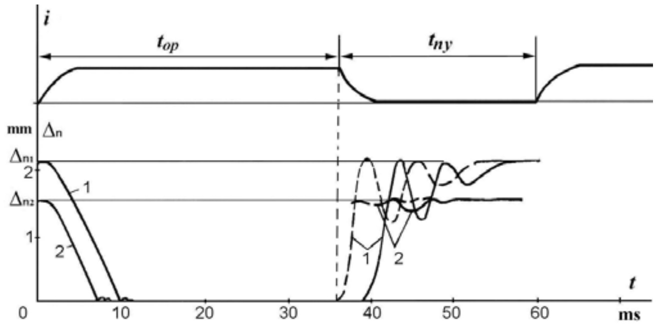


Fig. 9. Current (i) in driving coil and displacement of the blade in time for two (Δ_{n1}, Δ_{n2}) contact gap values with (solid line) and without (dashed line) diode applied to the energizing coil (K_o =1.5)

To suppress the blade vibrations under release the movable blade was equipped with especially shaped (like horse shoe) nonmagnetic but electroconducting support. Its lower part works as nonmagnetic pad between the blade (1) and filling pipe (3)-see Fig.8. Therefore, under open contact state the movable blade is preliminary pressed (by means of spring) to upper as well as to lower end of the support.

To avoid magnetic saturation of the blade during operation, its cross section was respectively increased. Both the blade and the support is wetted with mercury. Performance of this type reed can be compared from Fig.9 for two different contact gap ($\Delta_{1,2}$) values at overdriving factor K_o =1.5. As a result of application of preliminary force activity (oppositely directed) and due to increased mass of the movable contact system with presence of the mercury film on the contact surfaces the total operation time of the reed switch was increased what can be compared from Fig.7 and Fig.9 respectively. However, under releasing the blade vibrations, on the contrary, decays faster. Note, that the release time is increased when the diode is used.

Application of the movement limiter not only suppresses blade vibrations effectively but also improves heat outflow conditions from the blade volume under contact loading. On the basis of the investigations new structures of mercury wetted make type reed switches were developed. Among others the special structure (made in Russia) for operation with frequency of 16Hz (t_{ny}/t_{op}=0.7) under heavy load however, without any performance under electrical load was designed[6].Therefore, under closed contact state the mercury wetted reed is loaded with puls current value (10-15)A at frequency of 100Hz and duration of 20ms..While when it is open the voltage value around 12-13kV across the contact gap is applied for time shorter than this of lack of energization ($t \le t_{ny}$ =25ms).

Conclusions

Mercury wetted reed switches are still used in practice due to their prominent properties, particularly, under extreme load conditions (micro-as well as heavy load).However, they are not recommended for wide application since mercury is harmful for environment. Performance of the mercury wetted reed depends on actuation but is strongly related to the reed structure and hydrodynamic properties of mercury used for wetting of the contact surfaces. For the switch with the change-over reed structure its operation can be changed from the C contact type (break-before-make) to the D type (make-before-break) respectively. It depends on value of the overdriving as well as the duty factor of the coil energization. Owing to the mercury inside the contact area the contact bouncing under continuous operation with frequency up to about 60Hz, was found to be effectively suppressed. Therefore, new structures of the mercury wetted reeds with make contacts for heavy duty operations were able to be developed and involved in practice.

REFERENCES

[1] Shoffa V.N,Chromov S.V.,Cicerjukin V.N., Dawidow S.V.: Influence of way of energization on dynamic characteristics of the reed switches.Tech.Sred.Swiazi.1991,wyp 8 (in russian)

[2] Shoffa V.N.,Miedzinski B.,: Influence of conditions and ways of energization on performance and time of life of reeds.Proc.of Int. Conf. 1-3 Oct 2008,Izd.OOO Poligraf,2009 (in russian)

[3] Shoffa V.N.,Reed and reed switches. Izd.MEI.1993,pp288 (in russian)

[4] Patent USRR: Liquid wetted reed switch. No 1229837,kl:H 01 H 29/00 ,1986 No 17 (in russian)

[5] Patent USSR: Liquid wetted reed switch. No 1365157,kl H 01 H 29/00 1/66,1988,No 1 (in russian)

[6] Patent USSR: Liquid wetted reed switch. No 1788529,kl H 01 H 29/00, 1993,No2 (in russian)

***Authors**: prof. V.N. Shoffa, V.N .Cicerjukin, Moscow Electric Power Institute (MEI), Moscow e-mail: shoffavn@mail.ru;*

Prof.dr.hab.inż. B.Miedzinski, Politechnika Wrocławska, Instytut Energoelektryki, e-mail: bogdan.miedzinski@pwr.wroc.pl;

Dr X.Wang, Agriculture University of China, Beijing, e-mail: wangxin820117@gmil.com;