

## Relief Formation on the Plane: Principal Solutions, Investigation and Application for the Blind

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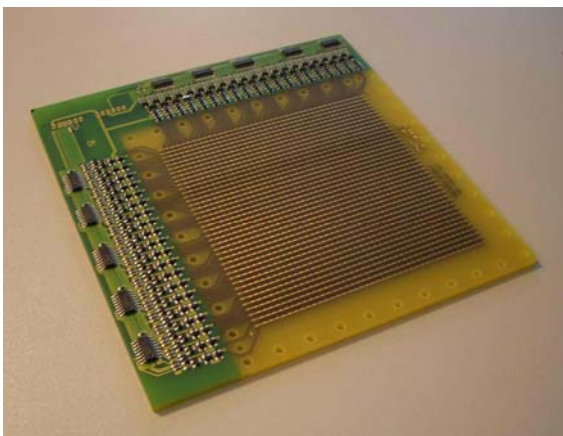
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### Introduction

The blind persons read and “view” by fingers. The Braille letters and relief of other graphic objects can be formed using valves controlled by electric field with electrorheological fluid ERF. The main part of valve is hole, filled by ERF. The viscosity of ERF varies, if strength of electric field varies, and the ridges of different height over holes can be formed, acting the valves with the same power. One valve forms height of one graphic point. Therefore, it is needed matrix of valves for relief formation. Usually one of control electrodes is mounted on axis of hole, other – on the wall of hole, or both electrodes – on the inner wall of hole [1]. When a large number of valves is involved, for example, in array manipulators or two-dimensional Braille devices (for which the number of valves may be 10000 and more), this approach is technologically complex.



**Fig. 1.** The matrix of controlled by electric field valves

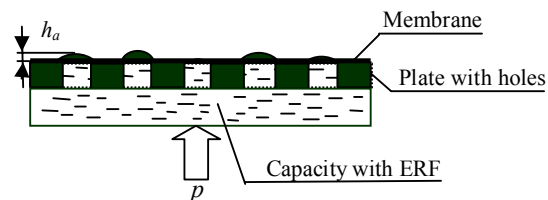
We investigate the original way of valve matrix realization, when the valve holes are made in standard both surfaces copper laminated textolit plate used in

electronics. This way has technological and economic advantages. Upper and lower copper surfaces are used, as electrodes for creation of electric field in the hole. To realize the possibility of independent voltage control of every hole the electrodes on the plates are made in a form of strips. The angle between them on both sides of the plate is equal to 90 degrees. The plate with 40x40 holes is showed in Fig. 1. It is created in KTU and made in firm Metec A/G.

The ridges over holes can be formed in different way. We investigate two possible constructions.

### Formation of ridges over valve holes

The first construction is showed in Fig. 2. It consists of capacity with electrorheological fluid ERF and of plate with holes, covered by elastic membrane. The height of ridge  $h_a$  over hole depends on the viscosity ERF in the hole, when the pressure  $p$  acts in the capacity with ERF. If the numerical relief is formed, the ridge over hole will be, when electric field is not created, and will be absent, when electric field acts.



**Fig. 2.** Formation of relief using membrane

The second construction is presented in Fig. 3. The pins, situated in every hole, are used for relief formation in this case. If impulse of the pressure  $p$  is created in the capacity with ERF, the height  $h_a$  of pins over plate level will be different depending on strength of electric field in

the hole. The pins can be metallic or dielectric. In the part of hole, filled by ERF, the electric field distribution will be different in the both cases.

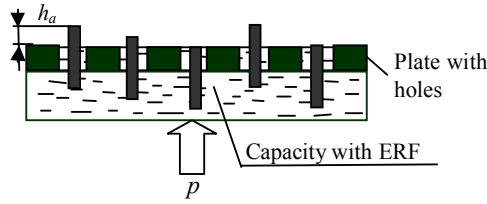


Fig. 3. Formation of relief using pins

The actual problem is clear up the construction, in which needed strength of field can be obtained with minimal voltage between electrodes of plate. The viscosity of ERF depends on the mean value of electric field strength. We compare the mean values of electric field strength for three cases: in the hole without pin, with dielectric pin and with metallic pin.

#### The mean value of electric field in the hole without pin

It is convenient to investigate electric field in the holes of constructions, showed in Fig. 2 and Fig. 3, as field in the hole of plane capacitor [2, 3].

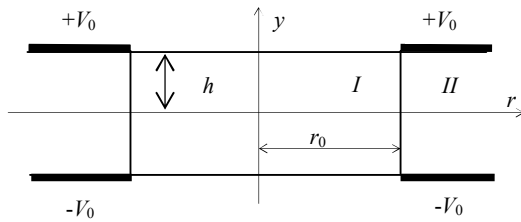


Fig. 4. Characteristics of hole

We use relative values of electric field strength and coordinates for hole, showed in Fig. 4:

$$E^S = E / E_0, \quad E_0 = V_0 / h, \quad r_s = r / r_0, \quad y_s = y / h, \quad (1)$$

where potential  $V_0$  is equal to  $1/2$  of voltage  $U$ , which acts between plate electrodes,  $h$  is equal to  $1/2$  of hole height,  $r_0$  is hole radius.

The analytical expression of electric field strength  $E^S$ , depending on  $r_s$  and  $h_s$ , was obtained for the wide hole in [2], using known distribution of electric field near the plane capacitor. The relative permittivity of ERF, filled the hole, is more than 1. In this case the distribution of electric field strength  $E^S$  can be calculated using modeling by finite element method. The modeling results of electric field strength  $E^S$ , when  $h=r_0$ , can be approximated for the textolite plate with relative permittivity  $\epsilon_{11}=7$  by the expression [3]:

$$E^S = K_1[1 - K_2 y_s^2] \cdot [1 + K_3 r_s^2] \cdot [1 + K_4 r_s^2 y_s^4]. \quad (2)$$

Coefficients  $K_1 - K_4$  depend on relative permittivity  $\epsilon_1$  of ERF:

$$K_1 = K_1(\epsilon_1) = \frac{1,03\epsilon_1}{0,027\epsilon_1^2 + 1,29\epsilon_1 - 0,12}, \quad (3)$$

$$K_2 = K_2(\epsilon_1) = \frac{0,893\epsilon_1 - 0,04}{0,912\epsilon_1 + 1}, \quad (4)$$

$$K_3 = K_3(\epsilon_1) = \frac{\epsilon_1}{2,96\epsilon_1 + 1,77}, \quad (5)$$

$$K_4 = K_4(\epsilon_1) = \frac{2,25\epsilon_1 - 1}{0,247\epsilon_1 + 1,61}. \quad (6)$$

The mean value of relative electric field strength  $\bar{E}^S$  can be calculated, as integral:

$$\bar{E}^S = \int_0^1 \int_0^1 K_1[1 - K_2 y_s^2][1 + K_3 r_s^2][1 + K_4 r_s^2 y_s^4] dr_s dy_s. \quad (7)$$

After integration we obtain

$$\bar{E}^S = K_1 \left[ \left(1 - \frac{K_2}{3}\right) \left(1 + \frac{K_3}{3}\right) + K_4 \left(\frac{1}{5} - \frac{K_2}{7}\right) \left(\frac{1}{3} + \frac{K_3}{5}\right) \right]. \quad (8)$$

Real mean value of electric field strength  $\bar{E}$  is:

$$\bar{E} = \bar{E}^S \cdot E_0. \quad (9)$$

The calculated  $\bar{E}^S$  values are presented in the first column of table 1 for some values  $\epsilon_f$ . They varies evenly in interval  $[0,79, 0,64]$ , when  $\epsilon_f$  varies in interval  $[1,7]$ . The  $\bar{E}^S$  increases, if  $\epsilon_f$  decreases. Therefore, strength of electric field increases using ERF with small  $\epsilon_f$  values.

The value of electric field strength is minimal on the axis and increases with  $r_s$  increase. Therefore, the mean value of electric field in ERF without pin will be always smaller, than the mean value in ERF near the pin, as the small values of  $r_s$  are occupied by pin.

#### The mean value of electric field in hole with dielectric pin

Electrorheological fluid fills the area outside the pin, and the mean value of electric field must be calculated in this area (fig. 5). If the radius of pin is  $r_a$ , the relative value of this radius will be  $r_{as}=r_a/r_0$ .

We calculate the mean value of electric field  $E_{r_{as}}^S$  in the volume, limited of  $r_s$  values, varying in interval  $[r_{as}, 1]$  and  $h_s$  values, varying in the interval  $[0,1]$ , for the case, when pin permittivity is equal to ERF permittivity. In this case the distribution of electric field will be the same as without the pin (see Fig. 5). The  $E_{r_{as}}^S$  can be expressed:

$$E_{r_{as}}^S = \frac{1}{1-r_{as}} \int_{r_{as}}^1 \int_0^1 K_1[1 - K_2 y_s^2][1 + K_3 r_s^2][1 + K_4 r_s^2 y_s^4] dr_s dy_s. \quad (10)$$

After integration we obtain:

$$E_{r_{as}}^s = K_1 \left[ \left(1 - \frac{K_2}{3}\right) \left(1 + \frac{K_3 K_{r3}}{3}\right) + K_4 \left(\frac{1}{5} - \frac{K_2}{7}\right) \left(\frac{K_{r3}}{3} + \frac{K_3 K_{r5}}{5}\right) \right], \quad (11)$$

where

$$\begin{cases} K_{r3} = 1 + r_{as} + r_{as}^2, \\ K_{r5} = 1 + r_{as} + r_{as}^2 + r_{as}^3 + r_{as}^4. \end{cases} \quad (12)$$

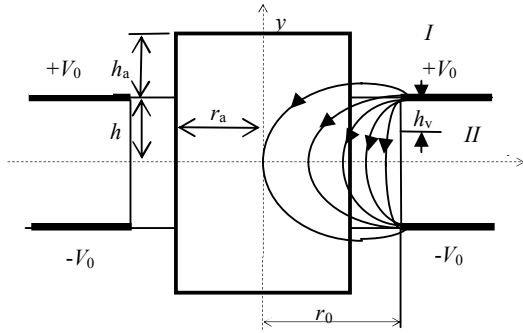


Fig. 5. The hole with dielectric pin

The results of calculation  $E_{r_{as}}^s$  for some values of  $r_{as}$  are presented in Table 1. We name an electrode zone the area outside pin with points, distant of electrode in  $y$  direction not more than  $h_v=0,5$ . The mean value of electrode zone electric field  $\bar{E}_{hv}^s$  was calculated for the case  $r_{as}=0,7$  using expression:

$$\bar{E}_{hv}^s = \frac{1}{(1-r_{as})(1-h_v)} \int_0^1 \int_{r_{as} h_v}^1 [K_1 [1 - K_2 y_s^2] [1 + K_3 r_s^2] [1 + K_4 y_s^4]] dr_s dy_s. \quad (13)$$

After integration we obtain:

$$\bar{E}_{hv}^s = K_1 \left[ \left(1 - \frac{K_2 K_{y3}}{3}\right) \left(1 + \frac{K_3 K_{r3}}{3}\right) + K_4 \left(\frac{K_{y5}}{5} - \frac{K_2 K_{y7}}{7}\right) \left(\frac{K_{r3}}{3} + \frac{K_3 K_{r5}}{5}\right) \right], \quad (14)$$

where

$$\begin{cases} K_{y3} = 1 + h_v + h_v^2, & K_{y5} = 1 + h_v + h_v^2 + h_v^3 + h_v^4, \\ K_{y7} = 1 + h_v + h_v^2 + h_v^3 + h_v^4 + h_v^5 + h_v^6. \end{cases} \quad (15)$$

**Table 1.** The mean values of electric field strength in all hole volume ( $r_{as}=0$ ),  $\bar{E}^s$ , outside pin,  $\bar{E}_{r_{as}}^s$ , for  $r_{as}=0,6, 0,7, 0,8$  and in electrode zone,  $\bar{E}_{hv}^s$ , for  $r_{as}=0,7$

$\varepsilon_1$	$\bar{E}^s$				$\bar{E}_{hv}^s$
	$r_{as}=0$	$r_{as}=0,6$	$r_{as}=0,7$	$r_{as}=0,8$	
1	0,789	0,867	0,885	0,949	0,798
2,4	0,735	0,854	0,884	0,916	0,816
3,8	0,701	0,835	0,870	0,907	0,860
5	0,684	0,827	0,863	0,899	0,864
7	0,639	0,785	0,822	0,864	0,834

We can compare the results, obtained for the mean values of electric field in ERF,  $E_{r_{as}}^s$ , and in the all volume of hole,  $E^s$ . The mean value electric field,  $E_{r_{as}}^s$ , calculated for the valve with dielectric pin, increases about 16% for  $r_{as}=0,6$ , about 20%, for  $r_{as}=0,7$ , and about 27% for  $r_{as}=0,8$  in comparison with the valve with membrane. The electric field increases, if ERF permittivity decreases, similarly to the case with membrane.

The electric field is pushed out of area with large value of permittivity into area with smaller values of permittivity. Therefore, the strength of electric field in ERF increases, if the pins with large values of permittivity are used. Varying pin permittivity at  $\varepsilon=7$  to  $\varepsilon=2,4$  we can increase the value  $E_{r_{as}}^s$  about 2-4%, when permittivity of ERF has value  $\varepsilon=2,4$ .

The pin height  $h_a$  over plate level has not significant influence to mean value of electric field  $E_{r_{as}}^s$  in ERF. If value of  $h_a$  is in limits  $[0, h]$ , the value of  $E_{r_{as}}^s$  does not vary more than 1%.

### The mean value of electric field in hole with metallic pin

The potential of metallic pin is the same in all pin volume. The electric field is absent inside pin, and all electric field is distributed outside pin (see Fig. 6).

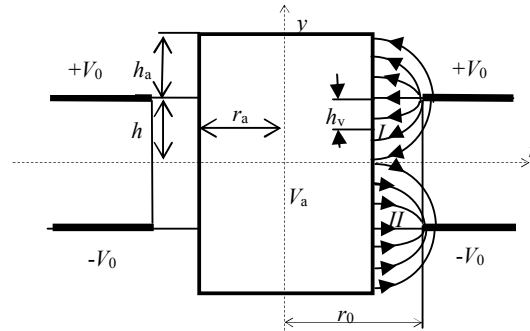


Fig. 6. The hole with metallic pin

At first, we suppose, that  $V_a=0$ . All electric field is distributed in the ERF volume with  $r_s$  values, varying in interval  $[r_a, 1]$ , and  $h_s$  values, varying in interval  $[0, 1]$ . Therefore, the mean value of electric field strength in the ERF volume is more, than using dielectric pin. It is large especially in the electrode zone, points of which are not far than  $h_v$  at any electrode in  $y$  direction. Using method of finite elements the mean value of electric field strength was calculated for some values of ERF permittivity. Modeling was made for case  $h_a=0$ , i.e., pin does not come out of hole. The mean value of electric field strength was calculated in all volume of ERF,  $\bar{E}^s$ , and in the electrode zone,  $\bar{E}_{hv}^s$ . The results are presented in Table 2.

**Table 2.** Mean values of electric field strength in all volume,  $\bar{E}^s$ , and in the electrode zone,  $\bar{E}_{hv}^s$ , for  $h_a=0$  and  $V_a=0$

$\epsilon_1$	$r_{as}=0,6$		$r_{as}=0,7$		$r_{as}=0,8$	
	$\bar{E}^s$	$\bar{E}_{hv}^s$	$\bar{E}^s$	$\bar{E}_{hv}^s$	$\bar{E}^s$	$\bar{E}_{hv}^s$
1	1,183	1,811	1,395	2,230	1,730	2,915
2,4	1,111	1,770	1,283	2,161	1,535	2,776
3,8	1,055	1,736	1,200	2,106	1,402	2,682
5,0	1,016	1,711	1,143	2,068	1,317	2,621
7,0	0,964	1,677	1,070	2,019	1,211	2,533

We can see, that the mean value of electric field strength  $\bar{E}_{hv}^s$  in electrode zone is more 1,5–2 times in comparison with the mean value in all ERF volume,  $\bar{E}^s$ . Using dielectric pin the mean value of electric field strength  $\bar{E}_{hv}^s$  in electrode zone is about equal to the mean value of electric field strength,  $\bar{E}^s$ , in all ERF volume (see 6th column of Table 1).

The results, presented in Table 2, were compared with the mean values of electric field in ERF, when pin is come out of hole. Modeling was made for height  $h_a=h$ , i.e., when the pin height is equal to half of hole height. The mean values  $\bar{E}_a^s$  and  $\bar{E}_{hva}^s$ , when pin with relative radius  $r_{as}=0,7$  is come out of hole, are presented in the Table 3

together with relative difference  $\Delta\bar{E}_a^s = \frac{\bar{E}_a^s - \bar{E}^s}{\bar{E}_a^s} \cdot 100\%$

and  $\Delta\bar{E}_{hva}^s = \frac{\bar{E}_{hva}^s - \bar{E}_{hv}^s}{\bar{E}_{hva}^s} \cdot 100\%$  from the values, when the pin is not come out of hole.

**Table 3.** The values of  $\bar{E}_a^s$  and  $\bar{E}_{hva}^s$ , when pin is come out of hole, and its relative differences  $\Delta\bar{E}^s \%$ ,  $\Delta\bar{E}_{hv}^s \%$  from the same values, when pin isn't come out of hole ( $V_a=0$ ,  $r_{as}=0,7$ )

$\epsilon$	$\bar{E}^s$	$\Delta\bar{E}^s \%$	$\bar{E}_{hv}^s$	$\Delta\bar{E}_{hv}^s \%$
1	1,39	-0,36	2,25	0,9
2,4	1,280	-0,23	2,161	0
3,8	1,194	-0,5	2,098	-0,38
5	1,138	-0,43	2,055	-0,63
7	1,065	-0,46	2,001	-0,89

Therefore, a change of metallic pin height  $h_a$  over ERF does not vary electric field in ERF, practically.

We investigate the electric field in ERF, when  $V_a \neq 0$ , for two cases:  $V_a=200$  V and  $V_a=400$  V, too. The hole was divided in two parts: I and II (see Fig. 6). I part is near the electrode with potential  $+V_0$ . This part is composed of points with coordinate  $y$  being in interval  $[0, h]$ , and  $r$  being in interval  $[r_a, r_0]$ . II part is near electrode with potential  $-V_0$  and consists of points, with  $y$  being in interval  $[0, -h]$  and  $r$  in interval  $[r_a, r_0]$ . The field decreases in I part and increases in II part in comparison with the case  $V_a=0$ .

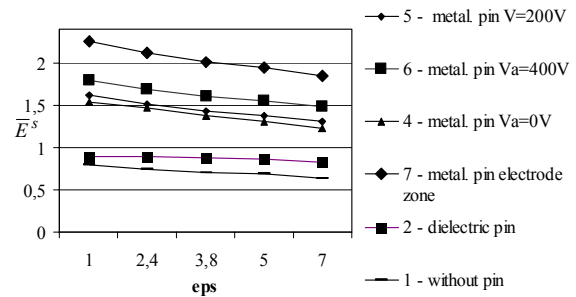
In the Tables 4 and 5 there are presented the mean values of electric field strength,  $\bar{E}_I^s$  and  $\bar{E}_{II}^s$ , calculated in the I and II parts, correspondingly, the mean values  $\bar{E}_{hvl}^s$  and  $\bar{E}_{hvlI}^s$ , calculated in the electrode zones, and average values  $\bar{E}^s = \frac{\bar{E}_I^s + \bar{E}_{II}^s}{2}$  and  $\bar{E}_{hv}^s = \frac{\bar{E}_{hvl}^s + \bar{E}_{hvlI}^s}{2}$ . The relative radius of pin is  $r_{as}=0,7$ .

**Table 4.** The mean values of electric field strength in I part,  $\bar{E}_I^s$ , in II part,  $\bar{E}_{II}^s$ , in all hole,  $\bar{E}^s$ , I electrode zone,  $\bar{E}_{hvl}^s$ , II electrode zone,  $\bar{E}_{hvlI}^s$ , and its average,  $\bar{E}_{hv}^s$ , when  $V_a=200$  V,  $h_a=0$ ,  $r_{as}=0,7$

$\epsilon$	$\bar{E}_I^s$	$\bar{E}_{II}^s$	$\bar{E}^s$	$\bar{E}_{hvl}^s$	$\bar{E}_{hvlI}^s$	$\bar{E}_{hv}^s$
1	1,113	1,815	1,464	1,751	2,719	2,235
2,4	1,046	1,664	1,355	1,700	2,629	2,165
3,8	0,996	1,553	1,275	1,660	2,559	2,110
5	0,962	1,479	1,220	1,632	2,551	2,071
7	0,918	1,388	1,153	1,596	2,449	2,022

**Table 5.** The mean values of electric field strength in I part,  $\bar{E}_I^s$ , in II part,  $\bar{E}_{II}^s$ , in all hole height,  $\bar{E}^s$ , I electrode zone,  $\bar{E}_{hvl}^s$ , II electrode zone,  $\bar{E}_{hvlI}^s$ , and its average  $\bar{E}_{hv}^s$ , when  $V_a=400$  V,  $h_a=0$ ,  $r_{as}=0,7$

$\epsilon$	$\bar{E}_I^s$	$\bar{E}_{II}^s$	$\bar{E}^s$	$\bar{E}_{hvl}^s$	$\bar{E}_{hvlI}^s$	$\bar{E}_{hv}^s$
1	1,011	2,276	1,643	1,292	3,213	2,253
2,4	0,972	2,093	1,532	1,257	3,102	2,179
3,8	0,942	1,964	1,453	1,229	3,016	2,123
5	0,921	1,881	1,401	1,209	2,958	2,084
7	0,893	1,780	1,337	1,183	2,882	2,032



**Fig. 7.** Dependence of mean values of electric field strength on ERF permittivity (eps) for different cases, if relative radius of pin  $r_{as} = 7$

The obtained results are generalized in Fig. 7. The 1 curve shows dependence between  $\bar{E}^s$  and ERF permittivity in hole without pin, 2 curve – in hole near dielectric pin, 3-6 curves – in hole near metallic pin, and 7 curve - the dependence between  $\bar{E}_{hv}^s$  and ERF permittivity near metallic pin.

Using dielectric pin we obtain maximal increment of mean value electric field in ERF 28,6% in comparison with case without pin. Using metallic pin, electric field in ERF increases 66,7%-76,2%, if  $V_a=0$ . Especially - 2,85-

3,13 times – the mean value of field increases in the electrode zones. These zones compose half of ERF volume in hole. If ERF stiffens in these zones, the valve closes and the pin will be fixed. If  $V_a \neq 0$ , the mean value of electric field is more in all ERF volume than in the case  $V_a = 0$ . But the mean value of electric field  $\overline{E}_{hv}^s$  is the same practically for any potential of pin  $V_a$  in the electrode zones. Therefore, it is sufficient to investigate the case  $V_a = 0$ .

## Conclusions

1. Desirable relief can be formed controlling by electric field viscosity of electrorheological fluid.
2. If the holes are made in both surfaces copper laminated textolite plate, electric field can be created, connecting voltage to upper and lower copper strips.
3. Relief can be formed using membrane, covering holes with electrorheological fluid or pins, sliding in the holes.
4. For the same voltage between plate electrodes the mean value of electric field in the electrorheological fluid is about 1,7 times stronger using metallic pins, and about

1,25 times stronger using dielectric pins than in hole without pin.

5. Using metallic pin the mean value of electric field in the half of ERF volume is about three times stronger than in hole without pin.

6. For the same voltage between plate electrodes the mean value of electric field in the electrorheological fluid increases with decrease of ERF permittivity and increase of pin and hole radii ratio.

## References

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**R. Bansevicius, J.A. Virbalis. Reljefo formavimas plokštumoje: principiniai sprendimai, tyrimas ir taikymas neregiamis // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2005. – Nr. 8(64). – P. 42–46.**

Elektriniu lauku valdant elektoreologinio skyscio klampuma kiaurymese, galima suformuoti Braille'o rasmenis ar kita norima reljefa. Kiaurymes isgrezus folijuoto tekstolito plokstete, elektrini lauka galima sukurti ijungiant itampa tarp plokstes elektrodu. Reljefa galima formuoti dvejopai: naudojant membrana, dengiancia kiaurymes su elektoreologiniu skysciu, ir naudojant adatelles, slankiojancias tose kiaurymese. Naudojant metalines adatelles, vidutinis elektrinis laukas elektoreologiniame skystyje buna apie 1,7 karto, o naudojant dielektrines adatelles, – apie 1,25 karto stipresnis negu kiaurymeje su membrana, esant tai paciai itampai tarp plokstes elektrodu. Naudojant metalines adatelles, elektrinis laukas ypac sustipreja srityse salia plokstes elektrodu. Taiskuose, kiaurymes asies kryptimi nutolusiuose nuo elektrodu ne toliau kaip per 0,25 kiaurymes aukscio, vidutinis elektrinis laukas kiaurymeje be adatelles buna apie 3 kartus silpnesnis. Elektrinio lauko stipris, esant tai paciai itampai tarp plokstes elektrodu, didėja mažėjant elektoreologinio skyscio dielektrinei skvarbai, taip pat didėjant adatelles ir kiaurymes spindulių santykiui. Il. 7, bibl. 3. (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

**R. Bansevicius, J.A. Virbalis. Relief Formation on the Plane: Principal Solutions, Investigation and Application for the Blind // Electronics and Electrical Engineering. – Kaunas: Technologija, 2005. – No. 8(64). – P. 42–46.**

The Braille letters or other relief can be formed in the matrix of holes filled by electrorheological fluid the viscosity of which is controlled by electric field. If the holes are made in the fabric-based laminate plate, the electric field can be created by voltage applied to electrodes of plate. Relief can be formed using membrane covering the holes or using pins sliding in the holes. The mean electric field in the electrorheological fluid using metallic pin is about 1,7 times stronger and using dielectric pin is about 1,25 times stronger than in the hole with membrane for the same voltage between the electrodes. The mean electric field increases especially in the array near the electrodes using metallic pin. The mean electric field is stronger about 3 times than in the hole without the pin in the points which are not longer than 0,25 of height of hole at top and bottom of hole. The strength of electric field increases if the permittivity of electrorheological field decreases or relation between radii of pine and hole increases for the same voltage between the electrodes. Il. 7, bibl. 3. (in English; summaries in Lithuanian, English and Russian).

**P. Бансевичус, Ю.А. Вирбалис. Формирование рельефа на плоскости: принципиальные решения, исследование и применение для слепых // Электроника и электротехника. – Каунас: Технология, 2006. – № 8(64). – С. 42–46.**

Управляя посредством электрического поля вязкостью электрореологической жидкости можно формировать шрифт Брайля или другой рельеф. Просверлив отверстия в плате, изготовленной из фольгированного текстолита, электрическое поле можно создать, приложив напряжение к электродам платы. Рельеф можно создавать двояко: используя мембрану, покрывающую отверстия с электрореологической жидкостью, или используя иглы, скользящие в отверстиях. Среднее электрическое поле в электрореологической жидкости, используя металлические иглы примерно 1,7 раза сильнее, а используя диэлектрические иглы примерно 1,25 раза больше, чем в отверстиях с мембраной при том же напряжении между электродами платы. В точках, удаленных в направлении оси отверстия не более чем на 0,25 раза высоты отверстия, среднее электрическое поле больше поля в отверстиях без иглы примерно 3 раза. Электрическое поле растет, если диэлектрическая проницаемость электрореологической жидкости уменьшается или отношение между радиусами иглы и отверстия возрастает при том же напряжении между электродами платы. Ил. 7, библи. 3. (на английском языке; рефераты на литовском, английском и русском яз.).

