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

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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.

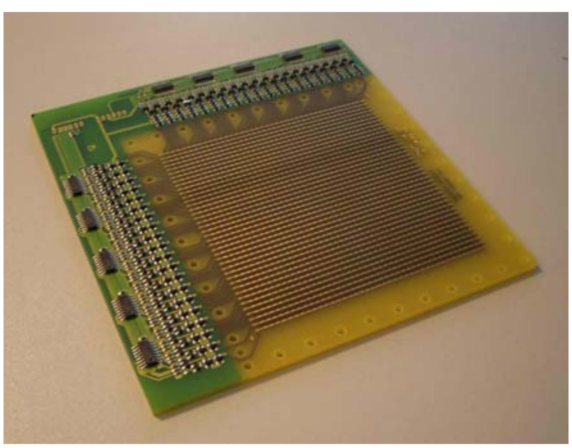

Fig. 1. The matrix of controlled by electric field valves

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.

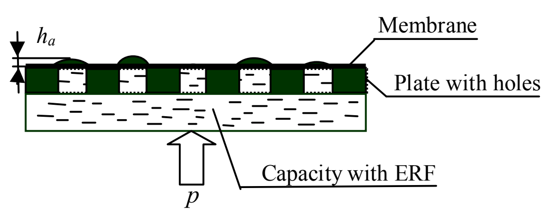

Fig. 2. Formation of relief using membrane

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.

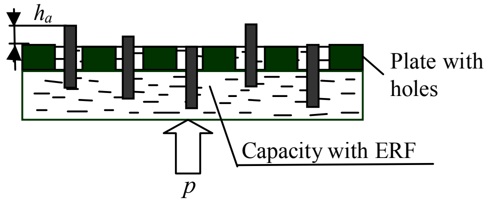

Fig. 3. Formation of relief using pins

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].

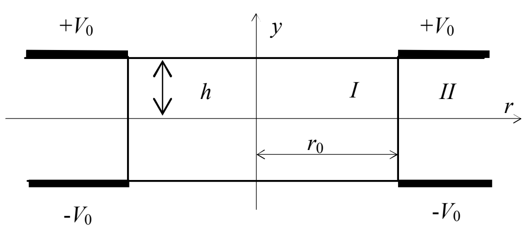

Fig. 4. Characteristics of hole

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 ½ of voltage U, which acts between plate electrodes, h is equal to ½ 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 ε_{II}=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 ε_I of ERF:

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

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

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

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

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

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

After integration we obtain

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

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

$$\overline{E} = \overline{E}^s \cdot E_0. \quad (9)$$

The calculated $\overline{E}^s$ values are presented in the first column of table 1 for some values ε_I. They varies evenly in interval [0,79, 0,64], when ε_I varies in interval [1,7]. The $\overline{E}^s$ increases, if ε_I decreases. Therefore, strength of electric field increases using ERF with small ε_I 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 $E^s_{r_{as}}$ in the volume, limited of r_s values, varying in interval [r_a, 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 $E^s_{r_{as}}$ can be expressed:

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

After integration we obtain:

$$E^s_{r_{as}} = K_1[(1-\frac{K_2}{3})(1+\frac{K_3K_{r3}}{3})+$$

$$+K_4(\frac{1}{5}-\frac{K_2}{7})(\frac{K_{r3}}{3}+\frac{K_3K_{r5}}{5})], \quad (11)$$

where

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

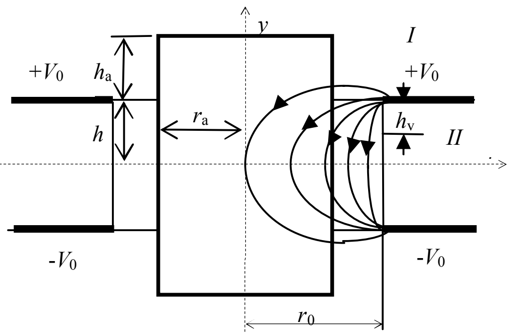

Fig. 5. The hole with dielectric pin

The results of calculation $E^s_{r_{as}}$ 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 $\overline{E}^s_{hv}$ was calculated for the case r_{as}=0,7 using expression:

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

After integration we obtain:

$$\overline{E}^s_{hv} = K_1[(1-\frac{K_2K_{y3}}{3})(1+\frac{K_3K_{r3}}{3})+$$

$$+K_4(\frac{K_{y5}}{5}-\frac{K_2K_{y7}}{7})(\frac{K_{r3}}{3}+\frac{K_3K_{r5}}{5})], \quad (14)$$

where

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

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

ε1	$\overline{E}^s$				$\overline{E}^s_{hv}$
	r_{as}=0	r_{as}=0,6	r_{as}=0,7	r_{as}=0,8	r_{as}=0,7
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, $E^s_{r_{as}}$, and in the all volume of hole, E^s. The mean value electric field, $E^s_{r_{as}}$, 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 ε=7 to ε=2,4 we can increase the value $E^s_{r_{as}}$ about 2-4%, when permittivity of ERF has value ε=2,4.

The pin height h_{a} over plate level has not significant influence to mean value of electric field $E^s_{r_{as}}$ in ERF. If value of h_a is in limits [0,h], the value of $E^s_{r_{as}}$ 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).

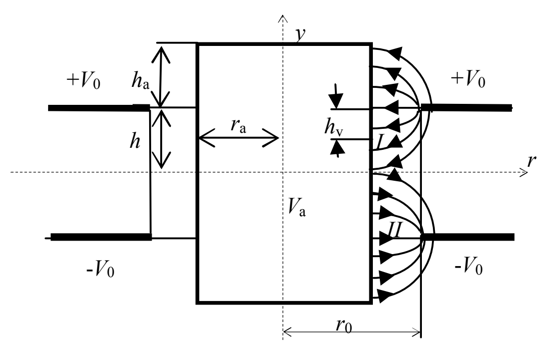

Fig. 6. The hole with metallic pin

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 came out of hole. The mean value of electric field strength was calculated in all volume of ERF, $\overline{E}^s$, and in the electrode zone, $\overline{E}^s_{hv}$. The results are presented in Table 2.

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

ε_1	r_{as}=0,6		r_{as}=0,7		r_{as}=0,8	
	$\overline{E}^s$	$\overline{E}^s_{hv}$	$\overline{E}^s$	$\overline{E}^s_{hv}$	$\overline{E}^s$	$\overline{E}^s_{hv}$
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 $\overline{E}^s_{hv}$ in electrode zone is more 1,5–2 times in comparison with the mean value in all ERF volume, $\overline{E}^s$. Using dielectric pin the mean value of electric field strength $\overline{E}^s_{hv}$ in electrode zone is about equal to the mean value of electric field strength , $\overline{E}^s$, 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 $\overline{E}^s_a$ and $\overline{E}^s_{hva}$, when pin with relative radius r_{as}=0,7 is come out of hole, are presented in the Table 3 together with relative difference $\Delta\overline{E}^s_a = \dfrac{\overline{E}^s_a - \overline{E}^s}{\overline{E}^s_a} \cdot 100\%$ and $\Delta\overline{E}^s_{hva} = \dfrac{\overline{E}^s_{hva} - \overline{E}^s_{hv}}{\overline{E}^s_{hva}} \cdot 100\%$ from the values, when the pin is not come out of hole.

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

ε	$\overline{E}^s$	$\Delta\overline{E}^s$ %	$\overline{E}^s_{hv}$	$\Delta\overline{E}^s_{hv}$ %
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, $\overline{E}^s_I$ and $\overline{E}^s_{II}$, calculated in the I and II parts, correspondingly, the mean values $\overline{E}^s_{hvI}$ and $\overline{E}^s_{hvII}$, calculated in the electrode zones, and average values $\overline{E}^s = \dfrac{\overline{E}^s_I + \overline{E}^s_{II}}{2}$ and $\overline{E}^s_{hv} = \dfrac{\overline{E}^s_{hvI} + \overline{E}^s_{hvII}}{2}$. The relative radius of pin is r_{as}=0,7.

Table 4. The mean values of electric field strength in I part, $\overline{E}^s_I$, in II part, $\overline{E}^s_{II}$, in all hole, $\overline{E}^s$, I electrode zone, $\overline{E}^s_{hvI}$, II electrode zone, $\overline{E}^s_{hvII}$, and its average, $\overline{E}^s_{hv}$, when V_a=200 V, h_a=0, r_{as}=0,7

ε	$\overline{E}^s_I$	$\overline{E}^s_{II}$	$\overline{E}^s$	$\overline{E}^s_{hvI}$	$\overline{E}^s_{hvII}$	$\overline{E}^s_{hv}$
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, $\overline{E}^s_I$, in II part, $\overline{E}^s_{II}$, in all hole height, $\overline{E}^s$, I electrode zone, $\overline{E}^s_{hvI}$, II electrode zone, $\overline{E}^s_{hvII}$, and its average $\overline{E}^s_{hv}$, when V_a=400 V, h_a=0, r_{as}=0,7

ε	$\overline{E}^s_I$	$\overline{E}^s_{II}$	$\overline{E}^s$	$\overline{E}^s_{hvI}$	$\overline{E}^s_{hvII}$	$\overline{E}^s_{hv}$
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

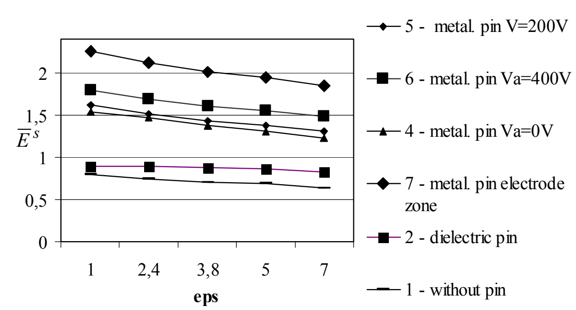

Fig. 7. Dependence of mean values of electric field strength on ERF permittivity (eps) for different cases, if relative radius of pin $r_{as} = 7$

The obtained results are generalized in Fig. 7. The 1 curve shows dependence between $\overline{E}^s$ 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 $\overline{E}^s_{hv}$ 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 textolit 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.

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Pateikta spaudai 2005 10 18

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Elektriniu lauku valdant elektroreologinio skysčio klampumą kiaurymėse, galima suformuoti Braille‘o rašmenis ar kitą norimą reljefą. Kiaurymes išgręžus folijuoto tekstolito plokštėje, elektrinį lauką galima sukurti įjungiant įtampą tarp plokštės elektrodų. Reljefą galima formuoti dvejopai: naudojant membraną, dengiančią kiaurymes su elektroreologiniu skysčiu, ir naudojant adatėles, slankiojančias tose kiaurymėse. Naudojant metalines adatėles, vidutinis elektrinis laukas elektroreologiniame skystyje būna apie 1,7 karto, o naudojant dielektrines adatėles, – apie 1,25 karto stipresnis negu kiaurymėje su membrana, esant tai pačiai įtampai tarp plokštės elektrodų. Naudojant metalines adatėles, elektrinis laukas ypač sustiprėja srityse šalia plokštės elektrodų. Taškuose, kiaurymės ašies kryptimi nutolusiuose nuo elektrodų ne toliau kaip per 0,25 kiaurymės aukščio, vidutinis elektrinis laukas kiaurymėje be adatėlės būna apie 3 kartus silpnesnis. Elektrinio lauko stipris, esant tai pačiai įtampai tarp plokštės elektrodų, didėja mažėjant elektroreologinio skysčio dielektrinei skvarbai, taip pat didėjant adatėlės ir kiaurymės spindulių santykiui. Il. 7, bibl. 3. (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

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The Braille letters or other relief can be formed in the matrix of holes filled by electroreological 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 electroreological 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 electroreological field decreases or relation between radii of pine and hole increases for the same voltage between the electrodes. Ill. 7, bibl. 3. (in English; summaries in Lithuanian, English and Russian).

Р. Бансявичюс, 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 отверстии. 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 отверстии с мембраной при том же напряжении между электродами платы. В точках, удаленных в направлении оси отверстия не более чем на 0,25 высоты отверстия, среднее электрическое поле больше поля в отверстии 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, библ. 3. (на английском языке; рефераты на литовском, английском и русском яз.).