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VARIABLERADIUS HELIX POTENTIOMETER: PRACTICAL ISSUES

Introduction

Potentiometer is a device converting a linear or rotary mechanical displacement into an electric signal. The most common quantity measured as its output is voltage. Potentiometers are utilized as transducers or as parts of more complicated devices, such as balanced bridge circuits and automatic potentiometers.

Although most potentiometers have linear taper, in some special cases non-linear taper is needed due to technical peculiarities of the problem to be solved. Such potentiometers, sometimes called “functional potentiometers”, are much more difficult to construct precisely enough to conform the desired taper. Many different approaches were proposed before. Rotary potentiometers are used most widely. For them the input value is rotation angle of the shaft, connected to controlled mechanism. Novice approach involves helical resistive element, radius of which is a function of shaft rotation angle. Its distinctive peculiarity is variable distance from shaft to the contact wiper. This approach has closed mathematical formulation, but none of practical sides has been analyzed yet. Thus, current paper is concentrated on issues, vitally important for applications: preferred generic design of a device and construction materials, manufacturing process, field for applications, pros and cons of the approach compared to other potentiometer types.

Problem formulation and its relevance

Parametric representation of a helical curve in cartesian coordinates $(x\,,\,y\,,\,z)$ is

$$\begin{cases} x = r(\varphi)\cos\varphi \\ y = r(\varphi)s\,\text{in}\,\varphi \\ z = b\varphi \end{cases}$$

$r(\varphi)$ is radius of the helix, parameter φ is a rotation angle of a point on the curve with respect to helix axis. Constant b might be expressed with helix pitch h as $b = h/2\pi$. Well-known special case for this is a cylindrical helix with $r(\varphi)$ = const. Cylindric helix has linear dependence of curve length on a value parameter φ. This property is utilized for multi-turn potentiometers, where a resistive element is compactly bended into a helix keeping linearity of “shaft rotation angle – output resistance/voltage” function. If $r(\varphi)$ is not a constant, the function will be non-linear. Taper of the potentiometer is proportional to the curve-length function. Given a function $r(\varphi)$, it’s an elementary task to find out the dependence of curve length on the parameter. However, an inverse problem is more difficult to solve. For a known curve length function $l(\varphi)$ shape of a helix might be found as a solution for an ordinary differential equation, called “helical equation”:

$$\frac{dr}{d\varphi} = +\sqrt{\left(\frac{dl}{d\varphi}\right)^2 - b^2 - r^2}\,.$$

This is a common initial value problem. Existence and uniqueness theorems approve a possibility to find a solution for a wide range of functions $l(\varphi)$, specifically all monotonic increasing smoothly differentiable functions. Thus, theoretically for any function $l(\varphi)$ with such properties one may construct a unique potentiometer in sense of unique function $r(\varphi)$.

Everything mentioned above leaves practice out of sight, i.e., construction, materials, manufacturing and calibration process. As long as science and engineering are continually developing, new opportunities available for producing different types of devices should be considered in the context.

Construction is the very first issue we must deal with. It includes type of resistive element and type of mandrel. This implies possible options for choice of materials. Manufacturing is mainly corresponding to mandrel, cause technologies for resistive elements (wire or film) of different types are known and might be applied for new constructions as well. Helix with variable radius is uncommon in technics, so that there is no technology aimed for direct manufacturing such geometric shape. Also, it's necessary to clarify the perspective of using such a potentiometer in technics.

Analysis of the recent publication and research works on the problem

In the field of devices for measurement of linear and rotary displacement, a great concurrence appears to be between different types of constructions and measurement principles, which measurement are based on. Here we consider only the most recent results, and some other works will be mentioned further in the paper. In articles [1–3], a comprehensive comparative study of different types of transducers is provided. More specifically, authors of [1] compare devices in context of their modular structure, treating each module separately. Work [2] is concentrated on the experience of using different kinds of devices in aerospace industry, taking into account pros and cons of each of them. Also, it includes some practical thoughts of necessity to develop a new sensor for a specific problem instead of using a standard one. In [3] one can also find some elaborations of current interest. Review papers [4–6] enlighten topic of displacement measuring devices in robotics. In work [4] this is connected with so called continuous (soft) robots, in [5] with industrial robotics, and in [6] with robotic hands. Works [7–8] are also examples of modern problems in the field which engineers are working on, exactly a problem of creating potentiometer for operating under high temperatures.

In the middle of XX century significant result on different types of resistive element were obtained. Author of [21] proposed an approach, similar to ours, with difference that it deals with planar curves only. This preserves constructors from difficulties due to variable mandrel radius, both mechanical and electrical. An approach to constructing non-linear photopotentiometers with variable output function was proposed in [22], i.e., the output function of a device can be changed by user. Also, it was mentioned in [14] that photopotentoimeters allow one to obtain a desired function from a rather wide variety of them. An analogical problem for contact pots was posed and solved in paper [23]. One construction of such potentiometer was patented in 1955 [24]. Its function may be varied by calibration of the total current length of resistive element using nested trimming pots.

A differential equation – the helical equation – was presented in a thesis work [9]. The equation describes geometry of a resistive element of the pot, depending on desired taper. Criteria of existence and uniqueness of solutions for the problem of calculation of such pot using that equation were formulated and proved in [10].

Formulation of the goal of the paper

The first purpose of the current paper is to find out types of construction, which are the most relevant for implementing non-linear tapered potentiometers with resistive element in form of a variable radius helix (VRH). The second purpose is to review branches of modern science and technics where such potentiometers might be utilized. Finally, it is necessary to make a conclusion about aim of further research.

1. Construction types of angle displacement transducers

Due to classifications given in [1, 3, 11, 12], we can distinguish the following angle displacement transducers types:

1. Purely mechanical.
2. Resistive (potentiometers themselves).
3. Capacitive.
4. Optical:
   - 4.1. light intensity meters;
   - 4.2. holographic;
   - 4.3. optical encoders;
   - 4.4. interferometers.
5. Hall-effect-based.
6. Magneto-resistive.
7. Inductance- and induction-based.
8. Gyroscopic.

Nowadays, resistive, magneto-resistive, inductance- and induction-based, optical and Hall-effect-based are the most popular in applications. Below, resistive, i.e., potentiometric transducers are classified by measuring principles and construction materials [1, 11–15]:

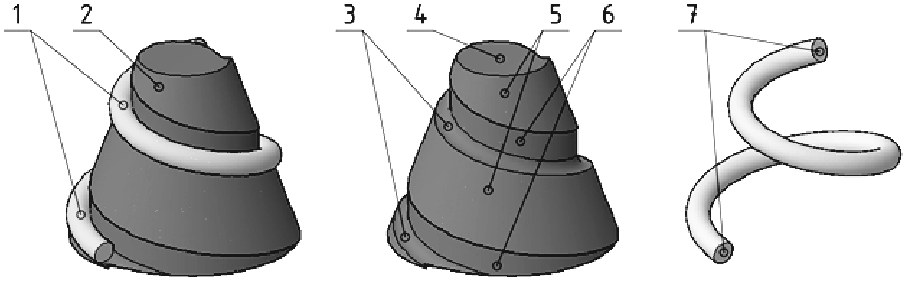
1. Contact:
   - 1.1. wirewound;
   - 1.2. film;
     - 1.2.1. metal;
     - 1.2.2. cermet;
     - 1.2.3. conductive plastic;
     - 1.2.4. carbon;
   - 1.3. liquid;
   - 1.4. electroosmotic;
   - 1.5. hybrid (film + wirewound).
2. Contactless:
   - 2.1. photoelectric;
   - 2.2. induction-based.

The following types, to our opinion, are the most appropriate for manufacturing: wirewound, film, hybrid and photoelectric. Now we'll take a closer look on each of them.

Multi-turn wirewound potentiometers of high precision usually have mandrel (frame, which resistive wire is winded on) of thick copper or duralumin wire [15, 26]. Because of high their plasticity, those materials are suitable for bending processing. In common multi-turn potentiometers mandrel is shaped into a cylindric helix, and for our approach, it may be shaped into VRH. The resistive wire is reeled on it before the mandrel shaping, so both processes, obviously, must be done accurately to keep the wirewound pitch constant.

Mandrel bending process itself may utilize a solid sample, which is a body of revolution. That sample has a channel cut in it. Pathway of the channel is tracing the shape of the mandrel which is to be made. The mandrel is then just put along the channel, resulting in a desired shape. If radius of the helix is a monotonic function of rotation angle, then ready-made resistive element might be separated from the sample, for the latter to be used for serial production. Otherwise, the sample must be designed in a way assuming that it will be a part of pot. The sample may look like one depicted on fig. 1. For manufacturing such an object a numeric controlled lathe and milling machine may be utilized. Another way of producing the sample is precise 3D-printing.

According to [15], one can use wire mandrel for film potentiometers, too. Thus, a film resistive element may be produced in a similar manner, or conduction material may be pulverized directly onto the sample from fig. 1. Hybrid pots have resistive element combined from wirewound and cermet/conductive plastic, and they are also potentially suitable for implementation.



a *b* *c*

Fig. 1. An example of a sample for reproducing resistive elements with monotonic radius. Designation: *a* – sample and a resistive element around it; *b* – sample; *c* – resistive element; 1 –resistive element, 2 – sample, 3 – channel for the wire, 4 – topface of the sample, 5 – side surface of the sample, 6 – vertical surface for possible separation of theresistive element, 7 – ends of the resistive elemen

Drawbacks of using wirewound potentiometers are well-known: stepwise changing output voltage; high mechanical noises, caused by transition of contact wiper along wire turns; limitations for rotation speed of the shaft because of worse performance with rapid rotation; limitations for AC frequency in the system due to inductance of the resistive element. Film pots are less affected by noise, and have unlimited resolution. However, their temperature coefficient is usually considerably larger than in wirewound devices. This is why combined resistive elements are used: they combine pros of wirewound pots (such as temperature coefficient and resistance stability) with long operational life, high resolution and low noise of film pots [11, 15]. On the other hand, the most precise potentiometers from some manufacturers [18] are actually wirewound.

Still all contact potentiometers share the same weaknesses: contact resistance and friction in elements. For that reason, we'll now take a look on contactless potentiometers.

Photoelectric potentiometers (or simply photopotentiometers) utilize photoelectric effect instead of direct contact between two conductors. This device has two conducting elements localized along the mandrel. One has high resistivity, and it is the resistive element itself. The other one, with low resistivity, acts as a long output contact. These two layers are separated by a layer of photoconductive element. The wiper is replaced with a light beam, which brings the photoconductive layer to increase its conductivity at a specific point. If resistive element is VRH-shaped, then both output contact and photoconductor layer must have such shape. Resistance of the latter depends on the light intensity. There are two ways of keeping the photocurrent constant: either keep the distance from light source to mandrel constant or to try to provide lighting conditions so that distance variations become negligible. It should be mentioned, that no limitation on device size is imposed. For example, see a range of sizes in [16–18] and miniature LED in [20]. However, both ways increase complexity of the construction significantly. This is why we consider contact potentiometers as have better perspectives for implementation than contactless ones.

Finally, it is important to remark, that precision potentiometers are rarely used without preceding calibration. Different calibration methods are presented in [14]. They make it possible to reach much higher precision than any method of manufacturing of non-calibrated pots. That is why calibration techniques also must be used for a tremendous improve of the resulting device.

2. Potentiometer taper

Now let us consider some sorts of tapers, which are relatively easy to obtain constructing a resistive element with a simple dependence of helix radius on rotation angle. For an ideal wire with constant resistivity ρ and constantcross-section *S*, the dependence of resistance on rotation angle is calculated using the following formula:

$$R(\varphi)=\int_o^L \frac{\rho(\varphi)}{S(\varphi)}dl=\frac{\rho}{S}\int_o^L dl=c\int_o^\varphi \sqrt{r(\varphi)^2+r'(\varphi)^2+b^2}\,d\varphi$$

with multiplier $c=\rho/S$.

1. Conical helix with radius $r(\varphi)=k\varphi$:

$$R(\varphi)=c\int_o^\varphi \sqrt{k^2\varphi^2+k^2+b^2}\,d\varphi=ck\int_o^\varphi \sqrt{\varphi^2+\left(1+\frac{b^2}{k^2}\right)}d\varphi=$$

$$=\frac{ck}{2}\left(\varphi\cdot\sqrt{\varphi^2+\left(1+\frac{b^2}{k^2}\right)}+\left(1+\frac{b^2}{k^2}\right)\log\left(\varphi+\sqrt{\varphi^2+\left(1+\frac{b^2}{k^2}\right)}\right)\right)\Bigg|_0^\varphi .$$

Adding a constant value to function $r(\varphi)$ in the integrand is equivalent to moving graph of the function with a proportional displacement along the *OX* axis, and alters value of the constant term under the square root.

2. Parabola-like helix $r(\varphi)=k\varphi^2$:

$$R(\varphi)=c\int_o^\phi \sqrt{k^2\varphi^4+4k^2\varphi^2+b^2}\,d\varphi=ck\int_o^\varphi \sqrt{\varphi^4+4\varphi^2+\frac{b^2}{k^2}}d\varphi.$$

This integral is an elliptic integral and has no elementary antiderivative in a general case. For a partial case $k=b/2$ we can write down the following:

$$R(\varphi)=\frac{bc}{2}\int_o^\varphi \sqrt{\varphi^4+4\varphi^2+4}\,d\varphi=\frac{bc}{2}\int_o^\varphi (\varphi^2+2)d\varphi=\frac{bc}{2}\left(\frac{\varphi^2}{3}+2\varphi\right).$$

3. Exponent-like helix $r(\varphi)=e^{k\varphi}$:

$$R(\varphi)=c\int_o^\varphi \sqrt{e^{2k\varphi}+k^2e^{2k\varphi}+d=b^2}\,d\varphi=$$

$$*e^{k\varphi}=z;\varphi=\frac{1}{k}\log z;d\varphi=\frac{dz}{kz};\ z_1=1;\ z_2=e^{k\varphi}\ *$$

$$=\frac{c}{k}\int_1^{e^{k\varphi}} \frac{\sqrt{(k^2+1)z^2+b^2}}{z}dz=$$

$$=\frac{c}{k}\left(\sqrt{(k^2+1)z^2+b^2}+\frac{b}{2}\log\frac{\sqrt{(k^2+1)z^2+b^2}-b}{\sqrt{(k^2+1)z^2+b^2}+b}\right)\Bigg|_1^{e^{k\varphi}} .$$

Antiderivatives for the first and the third integrals were found in [25]. We can see that resulting functions are quite complicated, and using a microcomputer as an alternative way of direct computations in real time can meet some difficulties due to lesser computing power. Computations on microcomputers utilizing look-up tables is more effective compared to direct calculation, but this case needs more research with direct performance and quality comparison. However, simple functions may not be reproduced as simply as they can be with common non-linear pots.

Algorithm of calculating multi-turn potentiometer [14] foresees an opportunity to use variable wirewound pitch, either to improve linearity or to make taper of the potentiometer non-linear. Below, we compare the range of derivatives for taper of a common multi-turn pot and for one with VRH-shaped resistive element. For a common multi-turn, we are given an equation

$$\sqrt{\pi^2d^2+t^2}=\frac{dR}{dl}\cdot\frac{t}{R_m}. \tag{1}$$

where *R* is a resistance function, *l* is length of a resistive element from its origin, *t* is wirewound pitch, *d* is diameter of the wirewound (measured by the center line of the wire), R_m is resistance of one meter of the wire. Using a known expression for R_m:

$$R_m=\frac{\rho l}{S}=\frac{4\rho}{\pi d^2}.$$

and for infinitesimal length of a helix

$$dl=\sqrt{\frac{D^2}{4}+b^2}\,d\varphi.$$

We can find an expression for $dR/d\varphi$, which is more suitable for direct compare with the derivative for VRH-potentiometer. After substituting last two equalities in the (1):

$$\sqrt{\pi^2d^2+t^2}=\frac{dR}{d\varphi}\cdot\frac{\pi d^2t}{4\rho\sqrt{\frac{D^2}{4}+b^2}}.$$

Now we can derive formula for $dR/d\varphi$:

$$\frac{dR}{d\varphi}=4\rho\sqrt{\frac{D^2}{4}+b^2}\cdot\frac{\sqrt{\pi^2d^2+t^2}}{\pi d^2t}=$$

$$=\frac{4\rho}{d}\sqrt{\left(\frac{D^2}{4}+b^2\right)\left(\frac{1}{t^2}+\frac{1}{\pi^2d^2}\right)}.$$

For evaluating numeric values of this derivative, we assume the following heuristic values for potentiometer parameters : $D=10$ mm $=1\cdot10^{-2}$ m; $b=2$ mm $=2\cdot10^{-3}$ m; $d=1$ mm $=1\cdot10^{-3}$ m; $\rho=1$ (Ω·mm²/m) $=1\cdot10^{-6}$ Ω·m.

Then we have the numeric formula to calculate derivative value for all wire diameters, both for minimum and maximum pitch:

$$\frac{dR}{d\varphi} = 2,154\cdot 10^{-5}\sqrt{\frac{1}{t^2}+1,013\cdot 10^5}.$$

Results of calculations for different wire diameters are given in table 1. Notice that greater derivative values are obtained with thinner wire and smaller wirewound pitch.

Relation of the maximum to minimum values plays key role in this situation. The maximum for this ratio is reached for the thinnest wire, with exact value

Table 1

Resistance function derivative for all wire diameters

Wire diameter *r*, mm	Wirewound pitch, mm		Resistance function derivative, Ω	
–	minimum	maximum	For minimum pitch	For maximum pitch
0,03	0,06	0,3	0,36	0,072
0,04	0,07	0,31	0,31	0,070
0,05	0,08	0,32	0,27	0,068
0,06	0,09	0,34	0,24	0,064
0,08	0,12	0,36	0,18	0,060
0,10	0,14	0,38	0,15	0,057
0,12	0,16	0,40	0,13	0,054

Relation of the maximum to minimum values plays key role in this situation. The maximum for this ratio is reached for the thinnest wire, with exact value

$$\frac{R'_{\max}}{R'_{\min}} = \frac{0,36}{0,072} = 5.$$

The point now is to find the minimum ratio “maximum to minimum radius” for VRH-potentiometer, that ensures that the value calculated above is reached. For a rough estimate we can assume that derivative of the radius at extremal points is equal to zero. Then for VRH we can write down the following:

$$\frac{dR}{d\varphi} = \rho\frac{dl}{d\varphi} \approx \rho\sqrt{r^2(\varphi)+A^2}.$$

$$\frac{R'_{\max}}{R'_{\min}} = \sqrt{\frac{r^2_{\max}(\varphi)+A^2}{r^2_{\min}(\varphi)+A^2}} = 5.$$

$$r_{\max} = 5\cdot\sqrt{r(\varphi)^2_{\min}+\frac{24}{25}A^2} > 5\cdot r_{\min}.$$

$$\frac{r_{\max}}{r_{\min}} > 5.$$

It’s rather hard to calculate and construct such a potentiometer. The main problems arising here are providing a good contact for all values of radius and a convenient size of the device. Although VRH-shaped mandrel is suitable for providing a slowly varying derivative, it is not the best choice for rapidly changing functions. This factor must be considered during selection a specific device.

3. Applications

Applications for potentiometers are diverse. Although every application is using the variability of the resistance of a pot, we distinguish three main types of usage: as trimming potentiometers, as transducers and as actuators. Trimming potentiometer is an element, the only purpose of which is to calibrate a circuit to improve its characteristics, such as power consumption, stability or precision. Used as a transducer, potentiometer transforms linear or rotary displacement into an electric quantity, mainly voltage or resistance. Potentiometer cannot be used as an actuator itself, but is might be an element in a feedback loop of an actuating subsystem. Below, we are trying to give a relatively complete classification for the most common ones, based on [11, 13–15, 26]:

1. Trimming pots:
   1.1. tuning gain for audio devices;
   1.2. calibration unbalanced bridge circuit in case of non-stabilized power source;
   1.3. calibration of a precision power source;
   1.4. calibration of circuits utilizing operational amplifiers;
   1.5. constructing non-linear resistive circuits using piecewise-linear approximation.
2. Transducers:
   2.1. displacement measurement (distant transmission systems, where pots can act both as transmitters and as receivers);
      2.1.1. linear displacement measurement;
      2.1.2. angular displacement measurement;
   2.2. other physical quantities measurement (bridge schemes, intermediate transducers, automatic potentiometers and other indicating devices);
      2.2.1. temperature;
      2.2.2. liquid and quick materials level;
      2.2.3. pressure;
      2.2.4. rotation speed;
      2.2.5. content of a gas mixture component;
      2.2.6. pH.

3. Actuators:
    3.1. feedback loop for automatic balanced bridge circuits;
    3.2. automatic tracking systems.

For most applications mentioned above, a linear tapered potentiometer is the most appropriate option. Where non-linear pots were in use before, now microprocessor technique is widely spread. This is true for measuring loops and for computing circuits, many of which were analogue (including potentiometer-based) few decades ago [13–15]. Speculating of applications, which are nowadays served by non-linear tapered pots, we have mostly ones, where only a trimming pot is needed, for example, analogue audio players and electric guitars. Most of such devices have logarithmic or inverted logarithmic taper, where large derivative of the taper occurs.

Analyzing measuring circuits, presented in [26], we didn't observe a single potentiometer with non-linear taper. Moreover, making use of such pots can cause additional troubles with both manufacturing and utilizing such technology. This regards both analogue and digital circuits. For analogue circuits, the key point is a non-uniform scale, that is basically harder to reproduce precisely. For solutions with digital devices non-linearity, especially when large scale difference of measured values is present, manufacturers have to apply more precise computing and indicating elements. This is an argument for using a block structure of systems, where special modules are used for computing complicated functions if necessary, and all the non-linearities are regarded only for inside usage, e.g., for computation of a control signal in case of automatic control systems.

We also found out the following regarding usage of potentiometers in robotics [4–6]:

1. continuous (soft) robots, which were developed during two last decades, make no use of potentiometers at all;
2. significant new results in industrial robotics are not connected with field of potentiometers;
3. measuring circuits utilized in robotic hands include two types of potentiometers: common for measuring angular displacement and force sensing one for contact force measuring; however, the latter might be replaced with rotary pots, as it was demonstrated in [29];

After additional search in [27–33], we didn't notice any mention about non-linear pots, i.e., all innovations utilize only linear-tapered potentiometers. After an analogical search among works on automatic control systems a patent [19] was found. We excluded some results, published before 1975.Taper of potentiometer from [19] is on fig. 2.

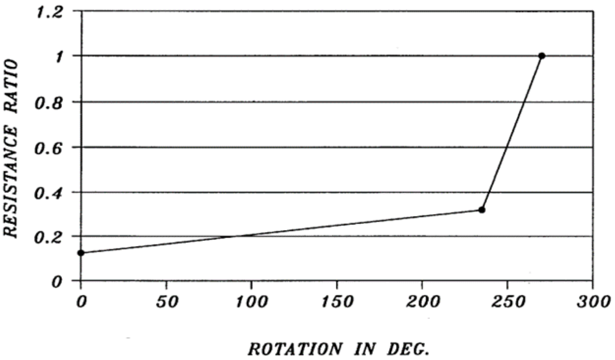


Fig. 2. Taper of a non-linear potentiometer for manual heat control

The patent relates to a heating system for an operator cab in a grapple skidder work vehicle. It utilizes a single trimming potentiometer, aim of which is to linearize the flow rate of heating fluid through a heat exchanger as a function of rotation angle of a controlling knob. This piecewise-linear taper might be replaced with a smooth taper of VRH potentiometer with a mandrel, shaped due to one of the variants proposed in section 2. The precise calculation of the target shape will be done in one of the future papers.

Research results

The best option for constructing such potentiometers are contact potentiometers, like wirewound, film or hybrid. A mandrel, produced of a flexible wire, is a good solution for keeping precision along with technological simplicity.

Discussed approach has several profits and drawbacks. The main advantages are:

1. Possibility of precise reproducing of predefined small non-linearities.
2. Possibility of analogue computations of complicated functions, like ones obtained in section 2.
3. All advantages of film and hybrid resistive elements are available, compared to wirewound potentiometers. Exactly: no resolution limits; no noise from contact wiper wound-to-wound transition; longer lifetime.

On the other hand, the following significant drawbacks must be considered:

1. Problems with providing good contact (for contact pots) for a given mandrel shape.
2. Provide constant contact resistance and wiper resistance encounters some difficulties for the same reason.
3. Impossible to reproduce a function with fast varying derivative.
4. Complicated mandrel shape for simple functions, such as x^2, $x^{1/2}$, sin x.
5. Possible large difference between minimum and maximum mandrel radius.
6. Potentially complex construction.

Also, we compared VRH approach with variable wirewound pitch approach for obtaining a non-linear taper. Variable wound pitch is preferable for functions with larger interval of derivative changing. This implies the 3rd item of the list above.

The main technical issues to be solved are providing good output contact, constant wiper and contact resistance, providing reliable calibration procedures. Also, common single-turn and multi-turn potentiometers utilizing conventional techniques for obtaining non-linear taper may be more appropriate in cases, where large derivative of the taper occurs, as it was shown in section 2. All these troubles and limitations must be carefully considered in work on a specific implementation and selecting them for applications. If the above problems are solved, our way of constructing a non-linear tapered pot will become a promising innovation in the field of precision non-linear potentiometers.

Following studies should firstly deal with challenges for obtaining a reliable and durable construction. Then it is necessary to examine solutions of helical equation on stability, boundness and possibility of extrapolation. Also, calculation of potentiometer for manual heat control should be done.

Conclusion

Several important issues regarding variable radius helix potentiometer were overviewed, exactly:

1. Suitable construction types and materials for implementing those constructions;
2. Manufacturing process;
3. Non-linear tapers for predefined simple mandrel shapes;
4. Use of such device in applied problems.

It was concluded, that VRH approach is mostly applicable for designing contact potentiometers, exactly wirewound, film or hybrid, compared with contactless types such as optical. Exact tapers were examined for some cases of predefined $r(\varphi)$: linear, quadratic and exponential functions. Obtained functions are difficult to compute, so that it is problematic to compute them directly in real time using microcomputers, but analogue computations speed on a VRH potentiometer does not depend on function. Digital computations with look-up tables need extra research for different functions for precision and performance comparison.

The following benefits of the construction were discovered: potentially high precision and resolution if film or hybrid resistance is utilized, and rapid evaluation of "time-expensive" functions. A generic way of manufacturing a mandrel for such potentiometer was proposed. An application as a trimming potentiometer in manual control system was proposed. Finally, perspective of further research was outlined.

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ГВИНТОВИЙ ПОТЕНЦІОМЕТР ЗМІННОГО РАДІУСУ: ПРИКЛАДНІ ПИТАННЯ

Нещодавно було запропоновано новий підхід до конструювання функціональних потенціометрів. Його суть полягає в тому, що бажана нелінійна залежність вихідної напруги від кута повороту досягається завдяки використанню резистивного елемента, що має форму гвинтової лінії зі змінним радіусом та сталим поперечним перерізом. Як було доведено раніше, задача розрахунку такого потенціометра має розв’язок для всіх неперервно диференційованих статичних характеристик .Однак практичність такої конструкції ще не встановлена. В даній статті оглянуто історичні та сучасні види потенціометрів, зокрема з нелінійними статичними характеристиками; матеріали, які використовують для їх виготовлення; деякі можливі статичні характеристики, отримані запропонованим способом; потенційні застосування. В розділі 1 ми *розглядаємо конструкції потенціометрів та матеріали, з яких їх виготовляють. Визначено типи конструкцій потенціометрів, найбільш придатні для втілення запропонованого підходу. Запропоновано загальний підхід для виготовлення каркасу й резистивного елементу гвинтових потенціометрів змінного радіусу за допомогою станків із числовим програмним керуванням. В розділі 2досліджено статичні характеристики потенціометрів для заданих наперед форм резистивного елементу. Проведено порівняння меж застосування гвинтових потенціометрів змінного радіусу та звичайних багатообертових потенціометрів зі змінним кроком обмотки. В розділі 3 розглянуто сфери застосування потенціометрів, проаналізовано їх використання в новітніх розробках в області робототехніки. Запропоновано використання гвинтового потенціометра змінного радіусу в системі ручного керування обігрівом кабіни транспортного засобу замість потенціометра з кусково-лінійною характеристикою. В розділі 4 зроблено висновки з проведених досліджень, зокрема структуровано переваги й недоліки конструкції. Окреслено завдання для подальшої роботи.*

Ключові слова: потенціометр; нелінійна статична характеристика; гвинтова лінія; вимірювальний пристрій; виконавчий пристрій.

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VARIABLE RADIUS HELIX POTENTIOMETER: PRACTICAL ISSUES

Recently a new approach to constructing potentiometers with non-linear taper was proposed. Its main idea is to reach a non-linear dependence of output voltage on rotation angle using a helical resistive element with variable radius of the helix and cross-section. As it has been shown before, problem of calculation of such potentiometer has a solution for all continually differentiable tapers, but the usefulness of this construction is still unknown. In the current paper we review historical and modern types of potentiometers, including non-linear ones; materials for manufacturing such pots; possible tapers for this type of construction; potential applications. In section 1 potentiometer constructions and materials are analyzed. Most suitable constructions for implementation of variable-radius-helix approach are chosen. A generic way for manufacturing mandrel and resistive element using modern machining tools with computer numeric control. In section 2 tapers for potentiometers with several predefined mandrel shapes are calculated. A comparison between appropriate taper bounds for VRH potentiometer and a conventional multi-turn with variable wirewound pitch is carried out. In section 3 different fields of potentiometer applications are reviewed, including usage of potentiometer in new works on robotics. VHR potentiometer is proposed for use in a manual control system for vehicle cab heating controllinstead of a potentiometer with piecewise-linear taper. In section 4 conclusions are made on perspectives of this type of potentiometer, its pros and cons. Main tasks for further research are outlined.

Keywords: potentiometer; non-linear taper; helix; transducer; actuator.

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