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FORMING IMPULSES FOR PARTIAL DEMAGNETIZING OF RARE-EARTH PERMANENT MAGNETS

ABSTRACT *In manufacture of facilities with permanent magnets there are some tasks when application of gauged magnitudes of magnetic characteristics of permanent magnets is required. In order to solve such tasks it is necessary to develop the methods of partial demagnetizing. Within an impulse magnetic field it is carried out at the expense of feeding series of impulses of demagnetizing field. For monitoring a level of a magnet field the carrying force P of the permanent magnet may be used.*

The choice of the law of impulse forming depends on the set requirements in an exactitude and productivity of the partial demagnetizing process. Process of partly demagnetizing assumes one-side approximation to a certain value of magnetization along the

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PROCEEDINGS OF ELECTROTECHNICAL INSTITUTE, Issue 229, 2006

magnetizing curve, beginning from the maximal value, without operations of partly magnetic bias of the permanent magnet when its magnetization decreased below the given level. Comparing the different laws of forming impulses is made using mathematical modeling of the partial demagnetizing process, based on real characteristics of permanent magnets.

Keywords: *rare-earth permanent magnets, impuls magnetizing methods*

1. INTRODUCTION

In manufacture of facilities with permanent magnets there are some tasks when application of gauged magnitudes of magnetic characteristics of permanent magnets is required. In order to solve such tasks it is necessary to develop the methods of partial demagnetizing. Within an impulse magnetic field it is carried out at the expense of feeding series of impulses of demagnetizing field. For monitoring a level of a magnet field the carrying force P of the permanent magnet may be used.

Different laws of forming series of impulses for realization of a partial demagnetizing are possible. The choice of the law of impulse forming depends on the set requirements in an exactitude and productivity of the partial demagnetizing process. Process of partly demagnetizing assumes one-side approximation to a certain value of magnetization along the magnetizing curve, beginning from the maximal value, without operations of partly magnetic bias of the permanent magnet when its magnetization decreased below the given level. Therefore the main requirement of this process is never to decrease below the required level of given parameter.

Comparing the different laws of forming impulses is made using mathematical modeling of the partial demagnetizing process, based on real characteristics of permanent magnets. These permanent magnets were demagnetized to the required level by the series of the impulses with using a small constant increase of voltage of the impulse current source. The carrying force of magnet P is a chosen controlling parameter. An initial spread of carrying force is 94 grams. The span of a required value of carrying is set by means of parameter ε and by means of central point of span. In our case, the span of a required value of carrying is 1950 ÷ 2050, and $P_{required}$ = 2000 *g*, ε = 50 *g*. The discrecity of a charging voltage of impulse current source is 1 V.

As a result of the various forming degaussing impulses laws' analysis we determined that the most effective laws of a partial demagnetization forming impulses are the "equal incline law" and the law, based on Kulinich's method.

2. THE EQUAL INCLINE LAW

At the given law of forming impulses each impulse is computed by formula:

$$U_{c\,i} = U_{c\,(i\text{-}1)} + k \operatorname{tg} \varphi \,(P_{i\text{-}1} - P_{required}) \tag{1}$$

where

$U_{c\,i}$ – a charging voltage of the battery in *i*-demagnetization cycle;

$P_{i\text{-}1}$ – a carrying force of a permanent magnet after the (i-1) demagnetizing impulse effect;

φ – the angle inclination of the step approximation chosen depending on the type of permanent magnet and required demagnetizing level $P_{required}$;

k – scale parameter.

Graphical interpretation of equal incline law is given in Fig. 1.

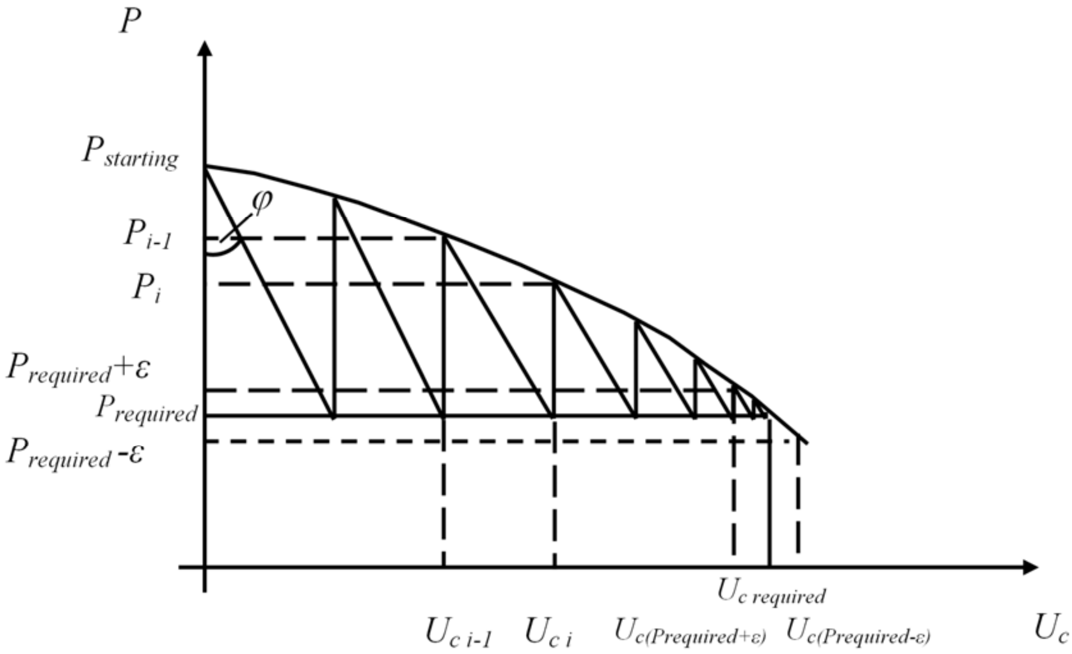

Fig. 1. Graphical interpretation of equal incline law

The tangent of an angle inclination *tg* φ can be determined by proceeding from a finite value triangle ABC (see Fig. 2) by formula:

$$tg\varphi_i = \frac{U_{ci(P_{required-\varepsilon})} - U_{ci(P_{required+\varepsilon})}}{(P_{i \cdot required} - \varepsilon) - (P_{i \cdot required} + \varepsilon)} = \frac{U_{ci(P_{required-\varepsilon})} - U_{ci(P_{recuired+\varepsilon})}}{2\varepsilon} \quad (2)$$

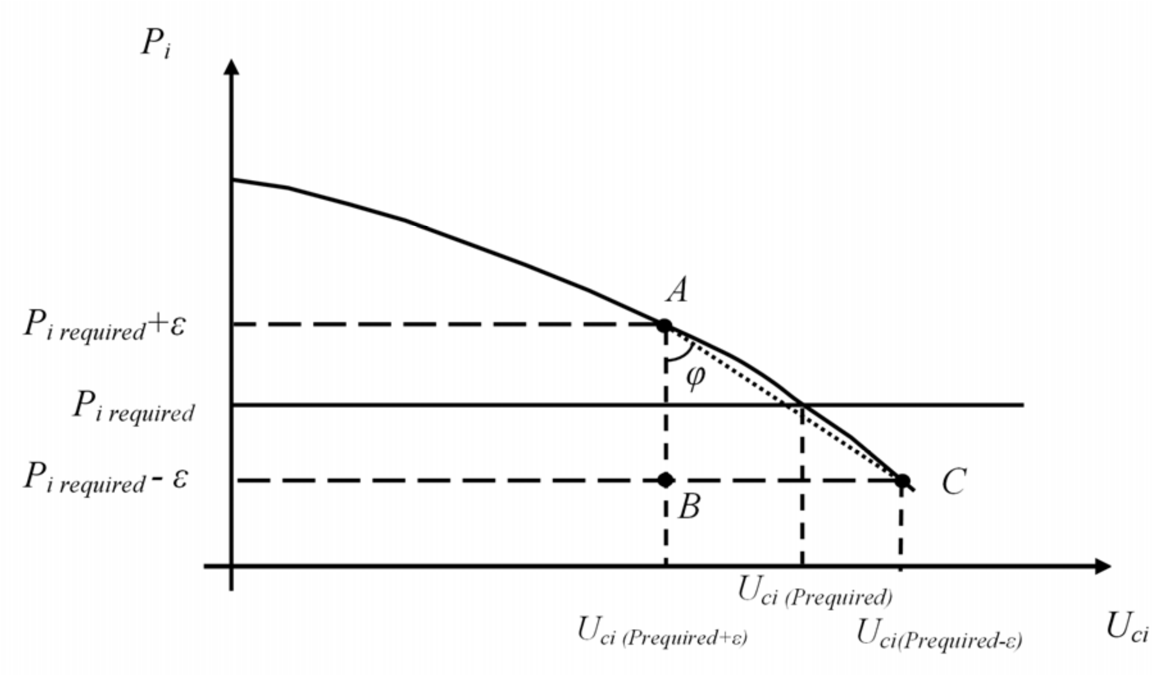

Fig. 2. The finite value triangle for determination of a tangent of an angle inclination

The block circuit of the algorithm of the law of equal incline law is given on Fig. 3. For its realization the input of following parameters is necessary: a required level of carrying force $P_{required}$, an angle inclination φ, minimum charging voltage $U_{c\,min}$, parameter ε(determines the span of a required value of carrying force). After that the charging voltage of impulse current source for the first impulse is set, the charge of current source is following and delivering of the given impulse to the inductor system for partial demagnetization of permanent magnet, up to a required level of carrying force. In case of the carrying force appears less upper bound of determines the span of a required value ($P_{required} + \varepsilon$) it is necessary to check, whether the carrying force has hit the span of a required value, by comparison of its value with value ($P_{required} - \varepsilon$). If $P_i > (P_{required} - \varepsilon)$ the process is considered to be successfully finished.

If P_i appeared less ($P_{required}$ - ε), the program shows a message to an operator about the low level of carrying force P_i.

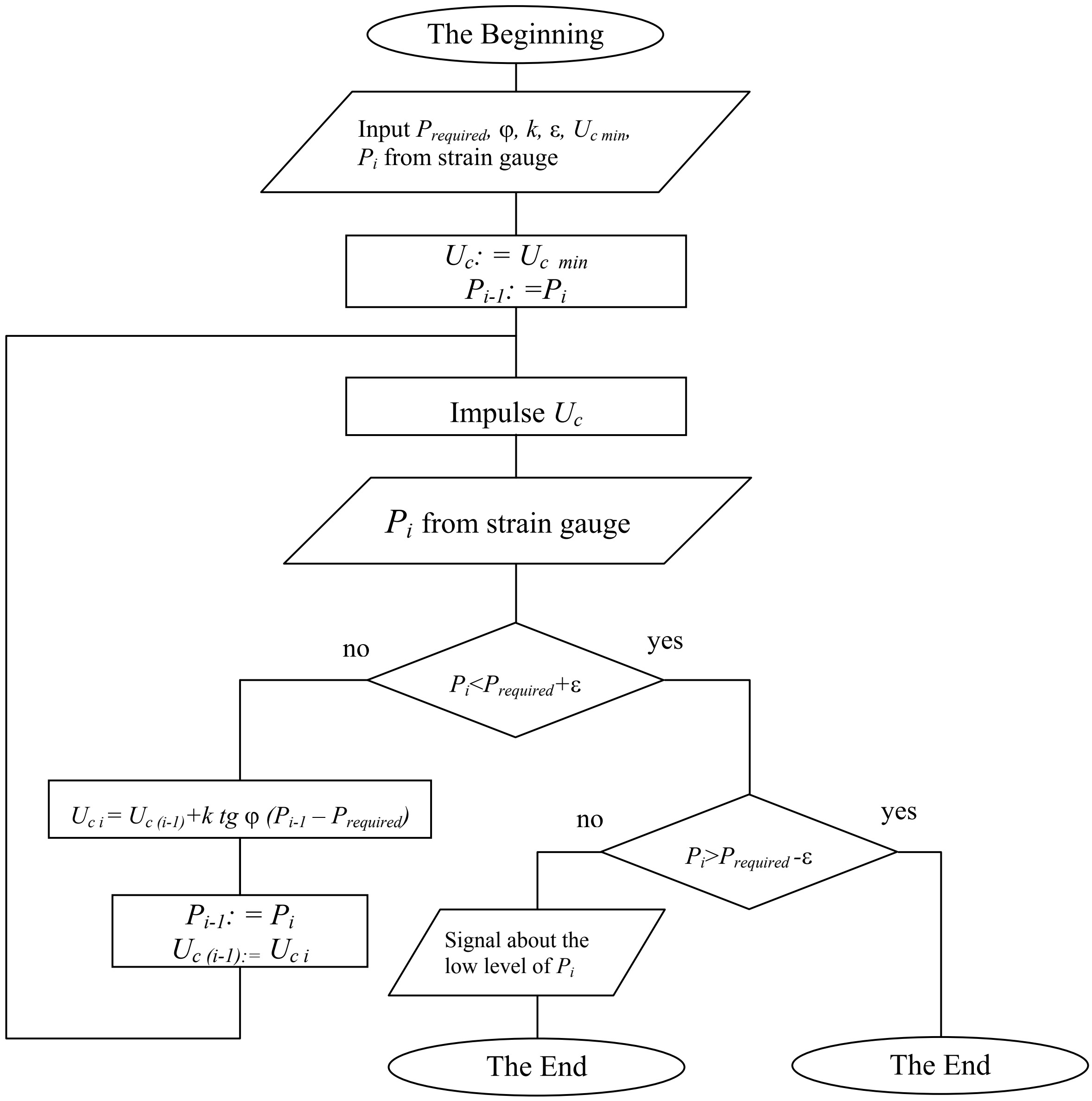

Fig. 3. The algorithm of the process of partial demagnetization using the equal incline law

If the carrying force P_i becomes higher than an upper bound of the span of a required value ($P_{required}$ + ε), computing of next impulse U_c by formula (1) follows, current value $U_{c\ i}$ is remembered in variable $U_{c\ (i-1)}$ (past impulse), the current carrying force P_i in variable P_{i-1} (past value of carrying force).

Virtues of the equal incline law are:

- Realization of the basic demand of a partial demagnetization at the correct selection of an angle inclination φ;
- A possibility of a speed-up of a partial demagnetization process by the starting from the initial voltage $U_{c\ min}$. A simple choice and correction of the given voltage within a batch of permanent magnets (voltage at which the magnet with a minimum coercive force will be demagnetized up to the given level).

The basic disadvantage of the given law of pulse forming is the strong dependence of a partial demagnetization process from an angle inclination φ which considerably increments number of cycles if the value of angle inclination φ is underrated, and can lead to omission of the basic demand of a partial demagnetization if the value of angle inclination φ is overestimated.

3. THE LAW BASED ON KULINICH'S METHOD

The method is based on input data description by the equations of dependency, the determination of parameters is based on definition of comparison coefficients of factorial and resulting attributes by the ration of separate values of the each attributes to its minimum or a maximum level [2].

On the basis of the finding the correlation of parameters it was explored at increment factorial and reduction of resulting attributes, taking the reducing range of parabolic association (at decrease of a resulting attribute after reaching a maximum), Fig. 4.

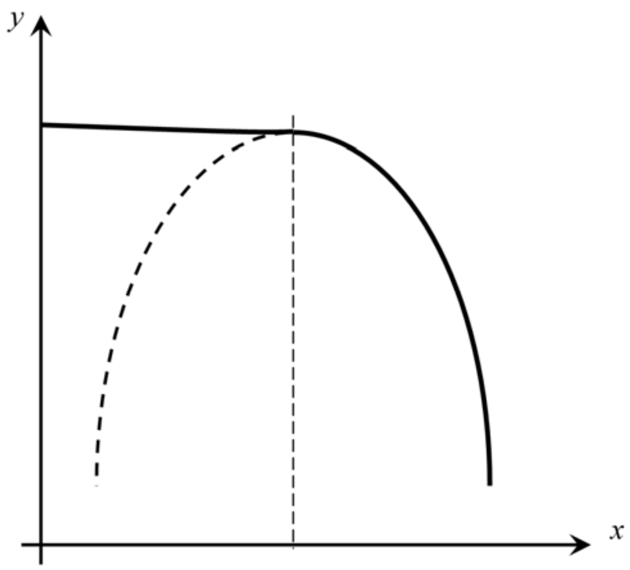

Fig. 4. The range of a demagnetization curve, which described by parabolic association, using the Kulinich's method

For computing the parameters of the equation, the curvilinear equation of the parabolic association adapted for finding was used:

$$y_{calc} = y_{\max}\left[1 - b(\frac{x_i}{x_0} - 1)^2\right] \quad (3)$$

where

y_{calc} – the equation of a reducing range of a parabola;

$y_{\max}$ – maximum value of a resulting attribute;

x_i – value of a factorial attribute;

x_0 – value of a factorial attribute at which the resulting attribute has a maximum level;

b – parameter of association.

For definition of the equation of a parabola it is necessary to compute parameter b. Knowing, that

$$\sum y_i - \sum y_{calc} = 0 \quad (4)$$

the evaluation of parameter of association *b* computes as follows:

$$\sum y_{calc} = \sum y_{\max}\left[1 - b\left(\frac{x_i}{x_0} - 1\right)^2\right] \quad (5)$$

Since the parameter of association b determines a lapse rate of decrease of a parabola for realization of the basic demand of a partial demagnetization it is necessary that

$$b = \max\{b_i\} \quad (6)$$

Thus, the realization of the automated partial demagnetization must be made in a following way:

- Initial impulse $U_{\min}(x_0)$is following; value of carrying force P_1 after the impulse it is $y_{\max}$;
- Proceeding from (3) of the next impulse will be computing by formula:

$$U_2 = U_{c\min}\left(1 + \sqrt{\frac{P_1 - P_{required}}{bP_1}}\right) \quad (7)$$

- In case there is no hit to the span of a required value after second impulse, third impulse computing by formula:

$$U_c = U_{c\cdot\min}\left(1+\sqrt{\frac{P_1 - 2P_{required} + P_2}{bP_1}}\right) = U_{c\cdot\min}\left(1+\sqrt{\frac{\sum_{i=1}^{2} P_i - 2P_{required}}{bP_1}}\right) \tag{8}$$

Generally, for *I-th* impulse the formula will become:

$$U_{cI} = U_{c\cdot\min}\left(1+\sqrt{\frac{\sum_{i=1}^{I-1} P_i - (I-1)P_{required}}{bP_1}}\right) \tag{9}$$

The block circuit of the algorithm of the based on Kulinich's method is given on Fig. 5

Input of following parameters is necessary for its realization: a required level of carrying force $P_{required}$, parameter of association b, minimum charging voltage $U_{c\ min}$, parameter *ε (*determines the span of a required value of carrying force).

After that the charging voltage of impulse current source for the first impulse is set, the charge of current source is following and delivering of the given impulse to the inductor system for partial demagnetization of permanent magnet.

After that the impulse of the carrying force P_i of permanent magnet, subjected to a partial demagnetization is determined.

Checkout follows: if it were the first impulse ($i = 0$). If yes, carrying P_i is remembered in variable P_1. If no, current value of carrying force P_i is added to variable P_s. Thus on I-*th* impulse variable P_s represents the sum of the carrying force measured from second up to (I-1) of-th impulse and is computed by formula:

$$P_s = \sum_{i=2}^{I-1} P_i \tag{10}$$

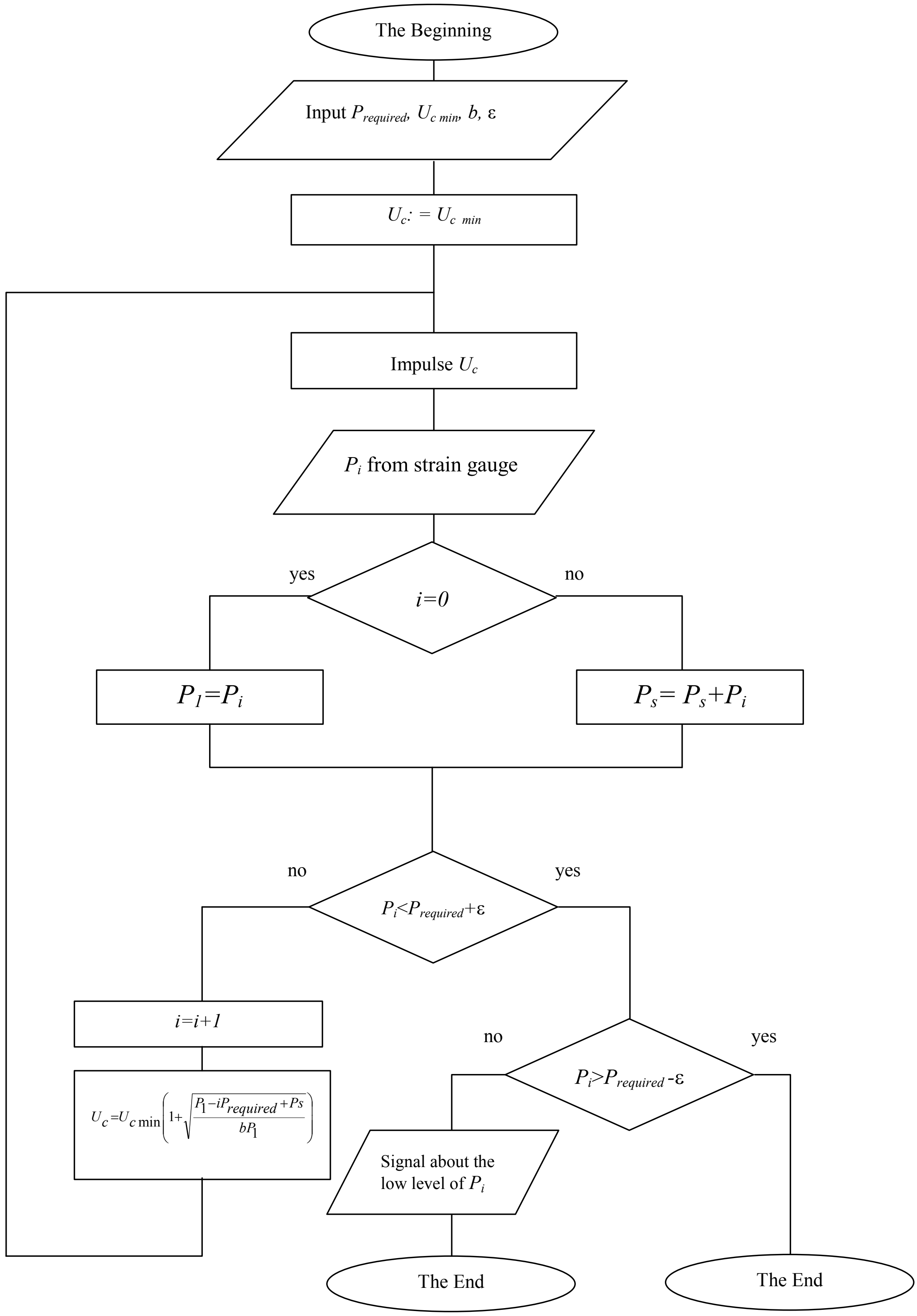

Fig. 5. The algorithm of the process of partial demagnetization using the law based on Kulinich's method

After the checkout of the value of a carrying force gained after impulse follows. In case the carrying force appears less upper bound of the span of a required value ($P_{required} + \varepsilon$) checkout follows: if the carrying force has hit in a the span of a required value, by comparison of its meaning with value ($P_{required} - \varepsilon$). In case $P_i > (P_{required} - \varepsilon)$ process is considered to be successfully terminated. If P_i it has appeared less ($P_{required} - \varepsilon$), the program shows a message to an operator about the low level of carrying force P_i. If the carrying force P_i appears above an upper bound of the span of a required value ($P_{required} + \varepsilon$), unit is added to a variable *i* (the given variable shows number of the yielded impulses). Account of next impulse U_c further follows by formula (9).

Virtues of the given method are:

- Realization of the basic demand of a partial demagnetization at the correct choice of parameter of association *b.*
- A split-hair accuracy and fast operation of a method.
- A stability of a method to ejections and the limited information (we shall apply at small samples).

The basic disadvantage of a method: the strong computing dependence from a choice of a point of imaginary maximum which determines from what value of a range of a curve of the demagnetization begins, described by Kulinich's method.

4. CONCLUSION

The lead analysis of the laws determining process of partial demagnetization of permanent magnets in a pulsed magnetic field, allows making following inference:

1. The equal incline law is the most universal as even at not optimum choice of initial parameters it allows to spend the automated partial demagnetization with a split-hair accuracy and fast operation.

2. The law based on Kulinich's method, has shown a split-hair accuracy and fast operation and can be used for automated partial demagnetization of permanent magnet, especially if permanent magnets inside of a batch have a wide spread of parameters.

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Manuscript submitted 14.11.2006
Reviewed by Barbara Ślusarek

FORMOWANIE IMPULSÓW DLA CZĘŚCIOWEGO ODMAGNESOWANIA MAGNESÓW TRWAŁYCH Z ZIEM RZADKICH

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STRESZCZENIE *W wyrobie produktów z magnesami trwałymi zachodzi konieczność stosowania określonych charakterystyk magnetycznych. W tym celu konieczne jest opracowanie metod częściowego odmagnesowania przez powodowanie szeregu impulsów pola odmagnesowującego. Dla obserwowania poziomu pola magnetycznego można użyć siłę nośną P magnesu trwałego. Wybór prawa, formowanie impulsu zależy od zadanych wymagań odnośnie dokładności i skuteczności procesu odmagnesowania. Proces częściowego odmagnesowania zakłada przybliżenie pewnej wartości namagnesowania wzdłuż krzywej magnesowania zaczynając od wartości maksymalnej bez działania częściowego magnetycznego magnesowania wstępnego magnesu trwałego gdy namagnesowanie maleje poniżej danego poziomu. Porównanie różnych praw formowania impulsów wykonuje się stosując modelowanie matematyczne procesu odmagnesowania, w oparciu o rzeczywiste charakterystyki magnesów trwałych.*