BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LVIII No. 2 bis / 2006	1-6	Seria Tehnică

Conception Design of a New Type of Absolute Encoder System (NAES) for Long Distance and Fine Accuracy

Alin Argeşeanu*, Ileana Torac**

* "Politehnica" University Timisoara, ** Romanian Academy-Timisoara Branch
e-mail: alin_argeseanu@yahoo.com, e-mail: ileana_torac@yahoo.com

Abstract

In this paper, the all- theoretical aspects of the new absolute encoder system (NAES) are shown. A succinct analyze offers the major advantages of the new linear encoder. In contrast with the classical binary linear encoder, the new solution presents a strong encoder ability, ideal for long distance applications (greater then 40m), a fine accuracy (0.5mm) and a very good reliability (the algorithm uses only 5 active tracks and 5 optical sensors). The practical application is the control of linear motors used in intelligent warehouses or factories.

Key words: *absolute encoder, combination algorithm, double encode action, new scale, micro steps.*

Introduction

For long distance applications (the length of the applications is minimum 9m and usual 40 m) it is impossible to use a classical absolute linear encoder with 0.5 mm resolution. A classical linear encoder, in the shorter application (for 9 m and 0.5 mm resolution), must codify 18000 segments. The binary codification of 18000 segments is possible to implement only using 15 bits (using 15 bits is possible to encode 32768 binary words). Practically speaking, the classical binary encoder needs a precision-graduated-scale with 15 tracks and an optical-head with 15 optical sensors. Such an encoder is unacceptable because of technical and economical conditions - low reliability and overcharge price.

For the 40 m application, using the same way, the number of encoded segments is 80000 and the number of bits in the binary words is 17.The conclusion is very clear: for these applications with long displacement and 0.5 mm resolution, the classical type of absolute linear binary encoder is not possible to be used.

Theoretical aspects of the new codification algorithm

The design of the new absolute linear encoder for long displacement, 0.5 mm resolution, starts from few ideas:

- the graduated scale is divided in a number of steps
- each step is encoded

- for each step is used also a fine resolution codification
- the combination of these two action-encode realizes a new encoder-concept

The absolute codification of the TF-LM steps is made using the mathematical concept of the combination computation. The new absolute linear encoder concept uses few different elements to encode the steps:

- each step is shared in sectors and the length of these sectors is used in the new codification algorithm;
- the scheme of the sectors for each step;
- the sign attached to each sector.

For the elucidation of the dissertation, it is shown particular and simple example, where the step is divided in 3 sectors, A, B, C, like in Fig. 1. If the step length is 40 mm, the sectors are:A=7 mm, B=13 mm, C=30 mm. Obviously, A+B+C=40 mm.

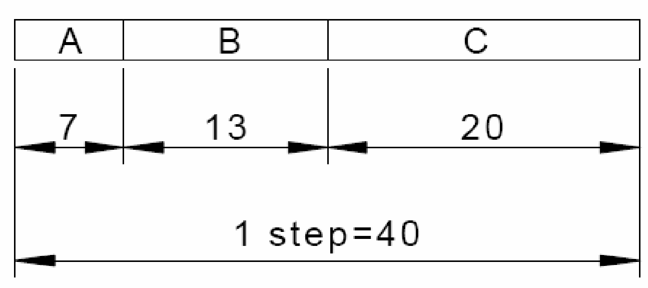


Fig. 1. The particular case of 3 sectors

The new algorithm uses elements of combination computation and, for this reason, it was named "combination algorithm" (CA). In the mathematical theory, with 3 elements, n=3, is possible to obtain maximum 6combinations:

If n=3, P (n) = n! = 6 and all 6 combinations of segments A,B,C are: {B, A, C}; {B, C, A}, {C, A, B}; {C, B, A}

When the sign information (+, -) are attached to all segments A,B,C, the maximum number of codified steps augments as follows:

- the first combination {B, A, C} is chosen
- it is accepted the symbolic convention:
    - A- for the positive sign, B- for the positive sign, C- for the positive sign
    - a- for the negative sign, b- for the negative sign, c- for the negative sign

The new set consequential to this observation is: ABC, aBC,ABc, aBc, AbC, abC, Abc, abc. Starting to the initial set {A,B,C}, and using the sign of the sectors, result 8 new sets, combinations. The maximum number of the 6 initial combination is 48: ABC; ABc; AbC; Abc; aBC; aBc; abC; abc;ACB; ACb;AcB; Acb: aCB; aCb; acB; acb:BAC; BAc; BaC; Bac: bAC; bAc; baC; bac:BCA; BCa; BcA; Bca: bCA; bCa; bcA; bca:CAB; CAb; CaB; Cab: cAB; cAb; caB; cab:CBA; CBa; CbA; Cba; cBA; cBa; cbA; cba;

In this way, using 3 sectors A,B,C with different length ($C\neq B\neq A$) and sign information for each sector (A,a,B,b,C,c) it is possible to obtain 48 combinations and to encode 48 steps of the displacement. Certainly, with only 3 segments A,B,C it is not possible to design an linear absolute encoder for long distance applications. But this example is utile like theoretical model. The maximum number of combinations, labels, (and this number is the maximum number of encoded steps), for k segments with sign, is :

$$N_{\max} = (k!) \cdot (2^k) \tag{1}$$

To implement this algorithm are necessary a new graduated scale and an optical head. The design of the new graduated scale is shown in the Fig. 2. It is presented only one step, encoded by the combination (aBc).

The new scale is made by 11 tracks (see in Fig.2):
1, 3, 5, 7, 9, 11 optical shields;
2 - step track- all steps are marked by successive white/black equal areas;
4 - segment length track- for each step, all segments A,B,C are marked by successive white/black areas;
6 - segment sign track- for each step the signs (+,-) are marked using the rule: white for positive and black for negative;
8 - first fine resolution track with successive white/black areas, with 1mm length;
10 - second fine resolution track with successive white/black areas with 1mm length. It is is out of phase with T/4.

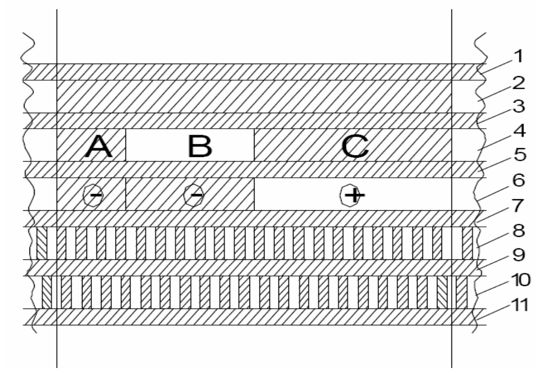


Fig. 2. The design of the new graduated scale**..**

Only five tracks are "active tracks" and need optical sensors. All optical shields are "passive tracks", without optical sensors. With this observation, is easy to design the optical head : one optical sensor for each active track, therefore are necessary five optical sensors.

The desirable accuracy (0.5 mm) is acquired like in Fig.2., using a logical function. If T_1, T_2 are the signals from the fine resolution tracks, the desirable accuracy is :

$$T_d = (\overline{T_1} + T_2)(\overline{T_2} + T_1) \tag{2}$$

Design of the new algorithm for long distance

The new algorithm for the absolute encoder of the long distances uses two types of codification: step codification (the true codification) and fine resolution codification (for every step). By this reason it is important to know the number of steps in every application. For the longer distance application (40m), the number of steps is 1000 (40mm each step). The length of the step is appointed by the linear motor characteristics. To expend very simple the number of coded steps is necessary to choose more segments for every step. If in the preceding paragraph the number of segment is k=3, for this particular case, with 1000 steps, the value of k result is k=5. It is important to observe the power of the new algorithm. Using only 5 segments, the maximum number of encoded steps becomes 3840. Our application uses 1000 steps and that mean 26.02%. If other application decides to use the full capacity of the algorithm for 5 segments and 0.04m the length of step, it is possible to encode 153.6 m. Another important observation is about the practical implementation. If the number of segments is changed, the number of active tracks keeps the same. When the number of active tracks don't change, also the design of the optical head don't change. Only the design of the graduated scale must be changed.

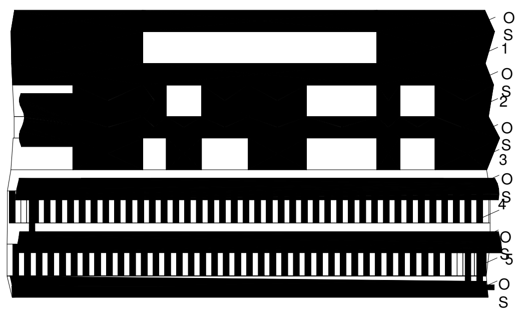
In the long distance application case, the number of segments is 5 : A, B, C, D, E. Without sign information, using 5 elements, the maximum number of code-words is 120 and all these combinations are:

{A, B, C, D, E}, {A, B, C, E, D}, {A, B, D, C, E}, {A, B, D, E, C}, {A, B, E, C, D},{A, B, E, D, C}, {A, C, B, D, E}, {A, C, B, E, D}, {A, C, D, B, E}, {A, C, D, E, B},{A, C, E, B, D}, {A, C, E, D, B}, {A, D, B, C, E}, {A, D, B, E, C}, {A, D, C, B, E},{A, D, C, E, B}, {A, D, E, B, C}, {A, D, E, C, B}, {A, E, B, C, D}, {A, E, B, D, C},{A, E, C, B, D}, {A, E, C, D, B}, {A, E, D, B, C}, {A, E, D, C, B}, {B, A, C, D, E},{B, A, C, E, D}, {B, A, D, C, E}, {B, A, D, E, C}, {B, A, E, C, D}, {B, A, E, D, C},{B, C, A, D, E}, {B, C, A, E, D}, {B, C, D, A, E}, {B, C, D, E, A}, {B, C, E, A, D},{B, C, E, D, A}, {B, D, A, C, E}, {B, D, A, E, C}, {B, D, C, A, E}, {B, D, C, E, A},{B, D, E, A, C}, {B, D, E, C, A}, {B, E, A, C, D}, {B, E, A, D, C}, {B, E, C, A, D},{B, E, C, D, A}, {B, E, D, A, C}, {B, E, D, C, A}, {C, A, B, D, E}, {C, A, B, E, D},{C, A, D, B, E}, {C, A, D, E, B}, {C, A, E, B, D}, {C, A, E, D, B}, {C, B, A, D, E},{C, B, A, E, D}, {C, B, D, A, E}, {C, B, D, E, A}, {C, B, E, A, D}, {C, B, E, D, A},{C, D, A, B, E}, {C, D, A, E, B}, {C, D, B, A, E}, {C, D, B, E, A}, {C, D, E, A, B},{C, D, E, B, A}, {C, E, A, B, D}, {C, E, A, D, B}, {C, E, B, A, D}, {C, E, B, D, A},{C, E, D, A, B}, {C, E, D, B, A}, {D, A, B, C, E}, {D, A, B, E, C}, {D, A, C, B, E},{D, A, C, E, B}, {D, A, E, B, C}, {D, A, E, C, B}, {D, B, A, C, E}, {D, B, A, E, C},{D, B, C, A, E}, {D, B, C, E, A}, {D, B, E, A, C}, {D, B, E, C, A}, {D, C, A, B, E},{D, C, A, E, B}, {D, C, B, A, E}, {D, C, B, E, A}, {D, C, E, A, B}, {D, C, E, B, A},{D, E, A, B, C}, {D, E, A, C, B}, {D, E, B, A, C}, {D, E, B, C, A}, {D, E, C, A, B},{D, E, C, B, A}, {E, A, B, C, D}, {E, A, B, D, C}, {E, A, C, B, D}, {E, A, C, D, B},{E, A, D, B, C}, {E, A, D, C, B}, {E, B, A, C, D}, {E, B, A, D, C}, {E, B, C, A, D},{E, B, C, D, A}, {E, B, D, A, C}, {E, B, D, C, A}, {E, C, A, B, D}, {E, C, A, D, B},{E, C, B, A, D}, {E, C, B, D, A}, {E, C, D, A, B}, {E, C, D, B, A}, {E, D, A, B, C},{E, D, A, C, B}, {E, D, B, A, C}, {E, D, B, C, A}, {E, D, C, A, B}, {E, D, C, B, A}

Using the sign information, for each combination is possible to find $2^5 = 3840$ new combinations. Here below, there are a part of all 3840 combinations, using the same rule:

A, B, C, D, E - positive sign
a, b, c, d, e - negative sign
(A, B, C, D, E},
(A, B, C, D, e}, (A, B, C, d, E}, (A, B, C, d, e}, (A, B, c, D, E}, (A, B, c, D, e},(A, B, c, d, E}, (A, B, c, d, e}, (A, b, C, D, E}, (A, b, C, D, e}, (A, b, C, d, E},(A, b, C, d, e}, (A, b, c, D, E}, (A, b, c, D, e}, (A, b, c, d, E}, (A, b, c, d, e},(a, B, C, D, E}, (a, B, C, D, e}, (a, B, C, d, E}, (a, B, C, d, e}, (a, B, c, D, E},(a, B, c, D, e}, (a, B, c, d, E}, (a, B, c, d, e}, (a, b, C, D, E}, (a, b, C, D, e},(a, b, C, d, E}, (a, b, C, d, e}, (a, b, c, D, E}, (a, b, c, d, E}, (a, b, c, D, e}, (a, b, c, d, e},
{A, B, C, E, D},
{A, B, C, E, d}, {A, B, C, e, D}, {A, B, C, e, d}, {A, B, c, E, D}, {A, B, c, E, d},{A, B, c, e, D}, {A, B, c, e, d}, {A, b, C, E, D}, {A, b, C, E, d}, {A, b, C, e, D},{A, b, C, e, d}, {A, b, c, E, D}, {A, b, c, E, d}, {A, b, c, e, D}, {A, b, c, e, d},{a, B, C, E, D}, {a, B, C, E, d}, {a, B, C, e, D}, {a, B, C, e, d}, {a, B, c, E, D},{a, B, c, E, d}, {a, B, c, e, D}, {a, B, c, e, d}, {a, b, C, E, D}, {a, b, C, E, d},{a, b, C, e, D}, {a, b, C, e, d}, {a, b, c, E, D}, {a, b, c, E, d}, {a, b, c, e, D}, {a, b, c, e, d},
…………………………………………………….
{E, D, C, B, A}
{E, D, C, B, a}, {E, D, C, b, A}, {E, D, C, b, a}, {E, D, c, B, A}, {E, D, c, B, a},{E, D, c, b, A}, {E, D, c, b, a}, {E, d, C, B, A}, {E, d, C, B, a}, {E, d, C, b, A},{E, d, C, b, a}, {E, d, c, B, A}, {E, d, c, B, a}, {E, d, c, b, A}, {E, d, c, b, a},{e, D, C, B, A} {e, D, C, B, a}, {e, D, C, b, A}, {e,

D, C, b, a}, {e, D, c, B, A}, {e, D, c, B, a},{e, D, c, b, A}, {e, D, c, b, a}, {e, d, C, B, A}, {e, d, C, B, a}, {e, d, C, b, A},{e, d, C, b, a}, {e, d, c, B, A},{e, d, c, B, a},{e, d, c, b, A},{e, d, c, b, a}
The principle of the new codification method for the NAES used applications demand length codification for all micro-steps: A=4mm, B=6mm, C=8mm, D=10mm, E=12mm.
This solution uses a special design for the coded ruler (scale) presented in Fig.3. for the step coded as **"aBcdE"**. The code principle for the micro-steps is:
a -black color (zero logic level); A - white color (one logic level)
b -black color (zero logic level); B - white color (one logic level)
c -black color (zero logic level); C - white color (one logic level)
d -black color (zero logic level); D - white color (one logic level)



b

Fig. 3. The design of the step aBcdE

In accordance with the Fig.3**,** the active tracks are:

1 - step track. this active track contains alternative black and white areas. Each area is 40mm length, the dimension of the step. The alternative arrangement of the areas (black and white) offers a very direct way to obtain information about the dimension of the displacement's steps.

2 - micro-step sign codification track. It is an active track that offers information about the length of all micro-steps. In this way, it is achieved the double codification of the micro-step: length codification and sign codification (positive/negative; 0/1 logic)

3 - micro step length codification track. It is an active track that offers information about the length of all micro-steps. In this way, it is achieved the double codification of the micro-step: length codification and sign codification (positive/negative; 0/1 logic)

4 - fine resolution-1 track (1mm resolution). The fine sign is displaced with T/4 in relation with the signs of the fine resolution-1 track. Using logical functions is possible to compose the signals acquired from the active tracks fine resolution 1 and 2 and to shape the needed fine resolution of 0.5mm. A minute aspect of both fine resolution active tracks is shown in the Fig.4a and Fig.4b. The 1mm space is divided in 2 identical parts a black and a white one (0 logic and 1 logic) and the displacement between the tracks is 0.25mm (T=1mm and T/4=0.25mm).

5 - fine resolution-2 track (1mm resolution)

Optimized variant of the new absolute encoder system

The standard variant of the NAES offers a remarkable reduction of active tracks number and optical sensors number, in relation with the classical absolute binary encoder. But for present works, an important technical and economical problem is to analyze all aspects concerning the reduction of active elements (tracks and optical sensors). The optimized variants offer a better price and, in the same time, better reliability level. By these reasons the first optimized variant proposes the reduction of the number of fine resolution tracks and, implicitly, the afferent number of optical sensors. The couple of fine resolutions tracks (active tracks no. 4 and no. 5) is replaced by one fine resolution track with double resolution. In the standard version the fine resolution is 1mm and there are necessary two active tracks, two optical sensors and a logical processing using function modulo2. For the optimized version is possible to use only one active track and one optical sensor, without the logical processing. A second optimized variant reduces the number of active tracks and implicates the number of optical sensors by removing an active track. The deleted active track is the **”step track".** Now, the design of the new coded ruler (scale) is given in Fig.5, where:

1 - micro-step sign codification track
2 - micro step length codification track
3 - fine resolution track

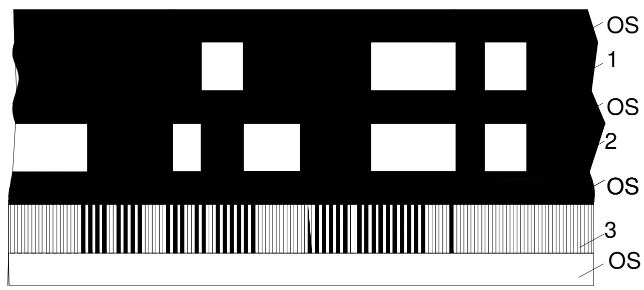


Fig. 5. The optimized design of NAES

.

References

1. Randy Frank, *Undersatnding Smart Sensors* 2nd ed, 2000 Artech House Publisher
2. R. Pallas-Areny, J. G. Webster, *Sensors and Signal Conditioning* 2nd ed, 2001 John Wiley&Sons
3. Keyence, General *Catalog Fiber OpticSensor 2005*
4. Keyence, General *Catalog Laser Sensor 2005*
5. A.Argeseanu, D. Teodorescu, *Noise Resection Circuit for the Balancing Machine* Patent RO-102697

Conceptele proiectării unui nou sistem de encoder absolut pentru distanțe mari şi acuratețe fină

Rezumat

Lucrarea prezintă conceptele de bază utilizate la proiectarea şi executarea unui nou tip de encoder absolut dedicat poziționării în cazul deplasărilor pe distanțe mari (peste 40m) şi acuratețe fină (0.5mm). Sistemul se bazează pe o dublă codificare: una de tip binar şi alta de tip codificare numerică a distanței. Sistemul de codare propus obține performanțele cerute cu un număr minim de senzori optici şi o riglă specială de codare. Prin optimizarea propusă, din cei 3 traductori optici doar unul este de performanță ridicată, respectiv cel care citeşte pista de rezoluție fină. In plus, se realizează şi bune performanțe de viteză, echipamentul satisfăcând condițiile impuse sistemului inteligent de poziționare.