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Algorithm and Program for Synthesis of Carousels for PVD Technology

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Abstract— Physical vapor deposition (PVD) is one modern pro-ecological technology for preparing thin layers with different properties and purpose. The carousels for the samples transportation are an almost indispensable element of the PVD equipment. This work describes an algorithm for their synthesis, which aims to collect maximum samples in the workspace. A program based on this algorithm has been designed and its various applications are discussed. An operating model of a triple rotation carousel has been generated with its help. Guidelines for future development of this program are shown. The versatility of the program makes it applicable to the synthesis of carousels of general purpose outside the PVD technology area.

Index Terms— algorithm, carousel, coatings, PVD, thin layers.

1 Introduction

Physical vapor deposition (PVD) is a topical proven technology for applying thin layers with different functions - for machining tools, optical elements, decorations, etc. [1]. Its application in machining industry has been developed quickly [2], [3], [4], [5], [6], [7]. The PVD layers exhibit very good performance in comparison with those similar coatings deposited by galvanic methods, chemical vapor deposition (CVD), sol-gel or other traditional technologies. One of the greatest advantages of PVD is that it is environmentally friendly, which is why it increasingly replaces other technologies for deposition of thin films. Last but not least, this technology allows very precise control over the production process and its successful management respectively. The mentioned and many other advantages of the PVD lead to its rapid development in recent years [4].

A general point is that the PVD is a line-of-sight process [4], [8] and to achieve uniformity of the coating the entire surface of deposition is required periodically to pass through the vapour stream. Therefore transportation mechanisms for moving the samples in the chamber are used. As the vacuum chambers usually are cylindrical in shape, these mechanisms are carousels – Fig. 1.

In the most cases double- and triple rotation carousels are used [10]. The geometry of the intrinsic arrangement and the gear ratios affect the structure of the layers, especially when it relates to the nanostructured layers [2], [4], [10], [11], [12], [13]. So these characteristics are not chosen at random and there are some special rules. However, the application of these rules is done after answering the question how much samples will be processed. This is particularly the task of the considered algorithm and program: with given initial geometric conditions of the environment to find solutions that allow one to collect the greatest number of samples in the chamber. Thus two major problems are solved for seconds.

First, one can realize the maximum amount of workpieces per working cycle very quickly and determine what the unit price will be.

Second, if the results of the previous step are favourable then the designer will have all the necessary geometric data – the pitch circle diameters and number of the satellites. Thus it remains only to perform routine design work.

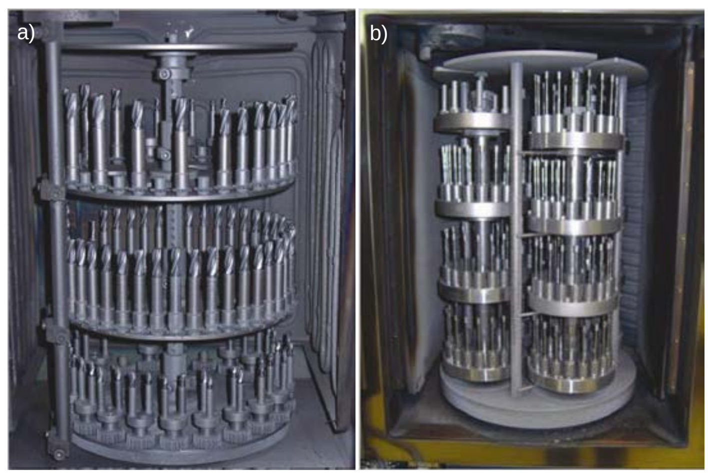

Fig. 1. Carousels for PVD technology: (a) double rotation carousel [9, p. 30] and (b) triple rotation carousel [9, p. 76].

The creation of the discussed program is related to the construction of carousels for processing machining tools by Electric Arc Deposition (EAD) – one of the varieties of PVD. However, the program can be successfully used for the synthesis of carousels not only in other sections of the PVD technology, but also in many other areas – knitting industry [14], machine-building [15] and even for amusing carousels [16]. A proper example of the application of triple rotation carousel is shown in Fig. 2.

To the best of author's knowledge, such a program does not exist. He had a practical need for similar one, but he could not find anywhere. With already created program couple of carousels have been simulated and made respectively.

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Fig. 2. Drag finishing machine [9, p. 48].

2 Algorithm

All satellites can be seen as a set of vertexes of a regular polygon. The main formula used by the program is:

$$D = \frac{b_n}{\sin\frac{\pi}{n}} \qquad (1)$$

where D is the circumscribed circle diameter, b_n is an edge of the polygon and n is the number of the edges of the polygon.

Operating data in the program are:

Input data: D - external diameter of the sample, D0 - internal diameter of the chamber, J0 - clearance between the carousel and the chamber, J1 - clearance between the double rotation satellites, J2 - clearance between the triple rotation satellites, J3 - clearance between the quadruple rotation satellites (Fig. 3).

Output data: N - maximal amount of samples in the chamber, D1 - pitch circle diameter of double rotation satellites, N1 - number of double rotation satellites, D2 - pitch circle diameter of triple rotation satellites, N2 - number of triple rotation satellites, D3 - pitch circle diameter of quadruple rotation satellites, N3 - number of quadruple rotation satellites (Fig. 3).

It is important to pay attention to the real significance of D (Fig. 4). In fact, it is the diameter of the largest circle which can be circumscribed about the pivot by the sample's rotation.

The algorithm of the program is shown in Fig. 5.

At first, input data are filled in. D and D0 (the diameters) are required to be greater than zero, while the remaining data J0, J1, J2 and J3 (the clearances) is required to be greater than or equal to zero. This means that the creation of a carousel without clearances between the components is allowed.

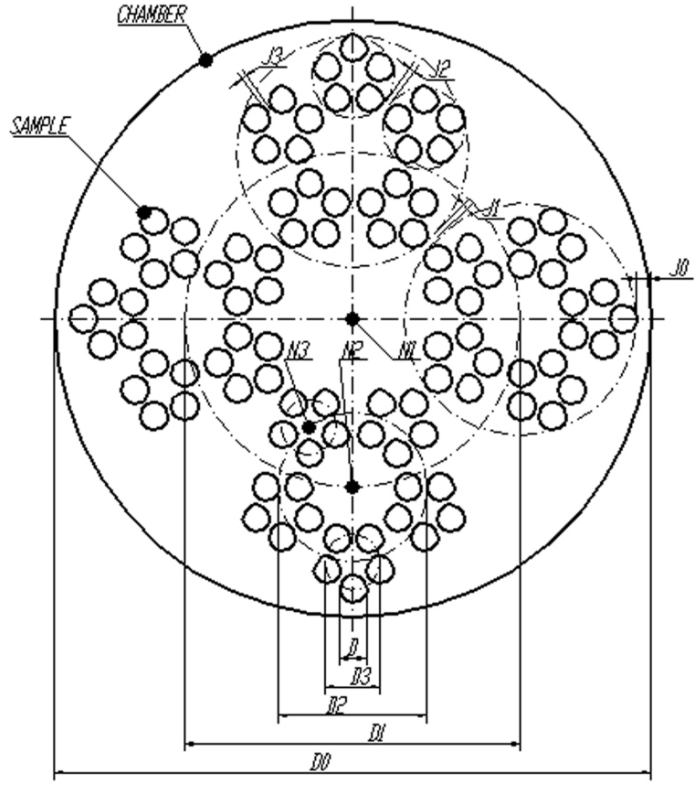

Fig. 3. Input and output data in the program.

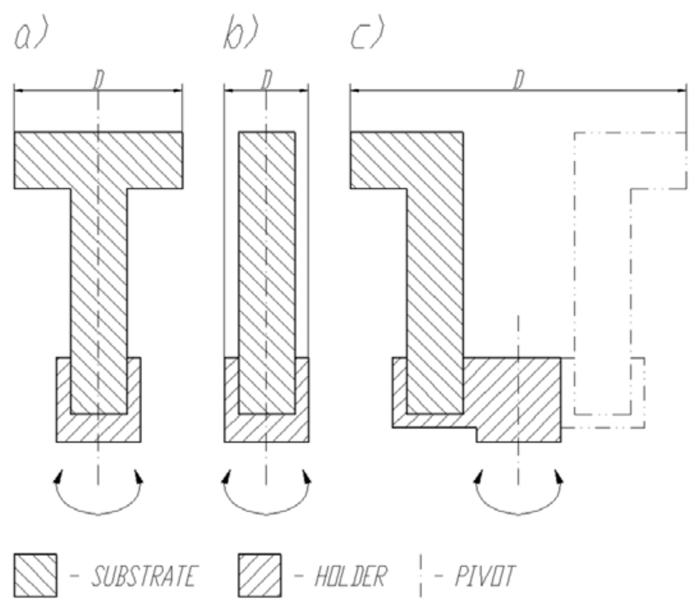

Fig. 4. Possible situations of sample rotation: (a) the substrate diameter is larger than the diameter of the holder, (b) the substrate diameter is smaller than the diameter of the holder and (c) asymmetrical substrate eccentrically located on the asymmetrical holder.

It does not matter what measurement units are used, it is important to be the same for all input data.

On the diagram (Fig. 5) the different stages where the main

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evaluation loops interrupt are marked.

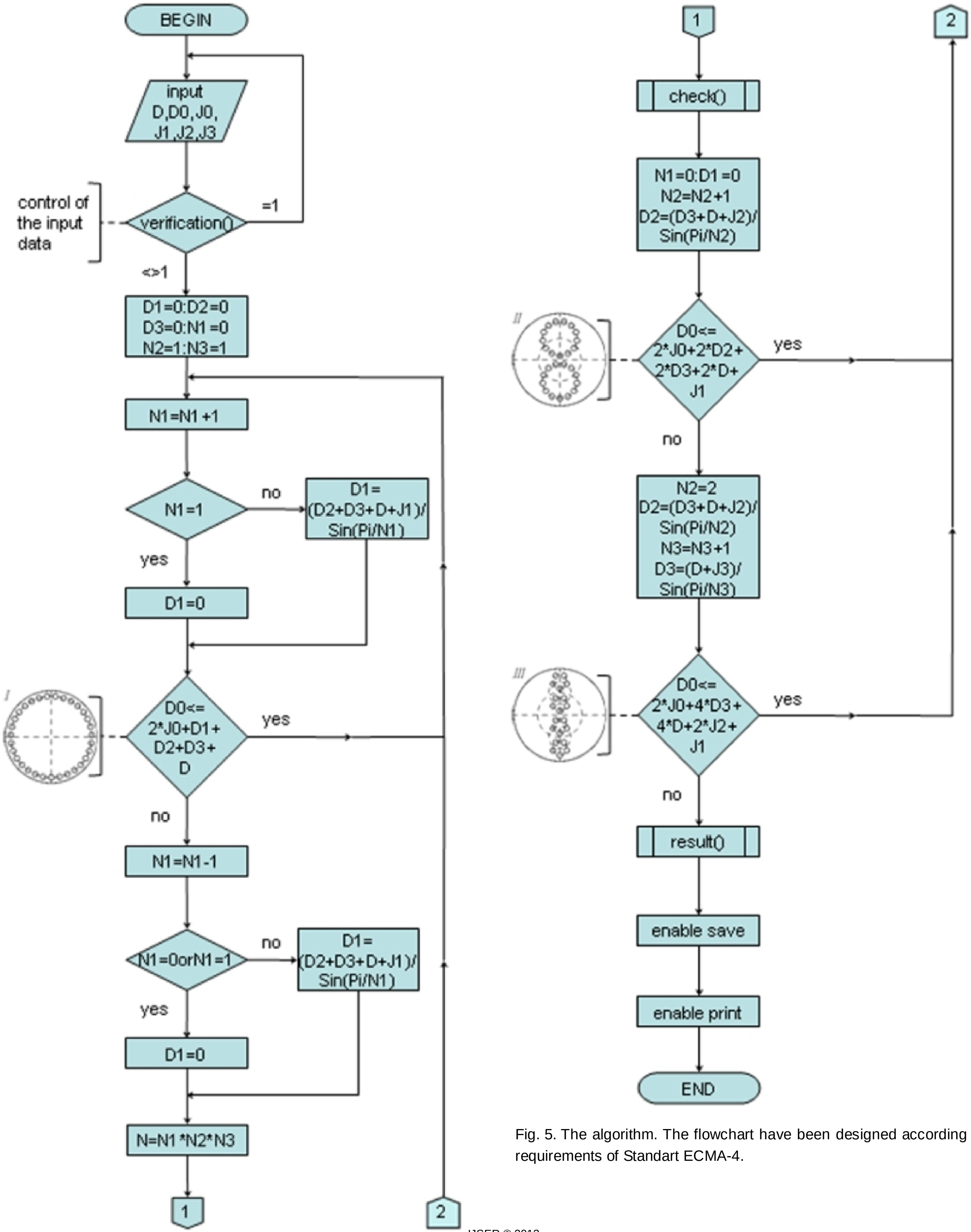

Fig. 5. The algorithm. The flowchart have been designed according to the requirements of Standart ECMA-4.

For Stage I the evaluation is interrupted when:

$$D0 > 2.J0 + D1 + D2 + D3 + D \qquad (2)$$

Thus all possible double rotation carousels are evaluated. For Stage II the evaluation is interrupted when:

$$D0 > 2.J0 + 2.D2 + 2.D3 + 2.D + J1 \qquad (3)$$

Thus all possible triple rotation carousels are evaluated. For Stage III the evaluation is interrupted when:

$$D0 > 2.J0 + 4.D3 + 4.D + 2.J2 + J1 \qquad (4)$$

Thus all possible quadruple rotation carousels are evaluated.

The following subroutines and functions are used:

verification () - verifies the suitability of the input data, displays a warning message and marks unallowable data if necessary.

check() – when the workspace is full, it compares the evaluated solution with the already existing and saved solutions. If this solution is better (greater N), then it replaces the previously saved solutions with this one. If it is equal (identical N), it adds this one to their list. Otherwise, the found solution is ignored.

result() - after the calculations it represents the output data.

One of the highlights is setting the values of N2 and D2 between stages II and III. This avoids consideration of triple rotation carousels in the evaluation of quadruple rotation carousels.

It should be noted that the closed component in the dimensional chain is J0 (clearance between the carousel and the chamber). In the proposed solutions of the program its value is always greater than or equal to the input value whereas J1, J2 and J3 retain their primary input values. On the one hand, this was done because the windages and inaccuracies in such construction most precisely reflect on J0 (especially under the influence of the centrifugal force). On the other hand, in this region of the PVD chambers special screens are usually placed which sometimes are very thin and undergo significant temperature warping. Naturally, the clearance could be distributed evenly between J0, J1, J2 and J3, and this would not significantly complicate the algorithm. If, however, the designer insists on keeping parity between these values, he/she may gradually increase simultaneously J1, J2 and J3 until they coincidence with the J0. These manipulations reflect only on the values of D1, D2 and D3, but not on N, N1, N2 and N3.

The presented algorithm can synthesize up to quadruple rotation carousels. Increasing the number of rotation axes is not a problem. This is justified for very large difference between the diameter of the chamber and diameter of the detail, such as processing tools for cutting of Printed Circuit Boards (PCB), Micro Equipment Technology (MET) [17], etc. It is enough to follow the algorithmic sequence exposed above.

Finally, the program calculates N (maximal amount of samples in the chamber) only for one floor of the carousel. To find the total amount of samples it is necessary to calculate how many floors will fit in the chamber. For this purpose the height of the workspace should be divided by the height of one floor. Rounding down to a whole number and multiplying by the program result (N), the quantity of all samples that fit in the working chamber can be found.

3 Program

The development environment Microsoft Visual Basic 2008 Express Edition [18] was used for the creation of the program. One can see the main window of the program in Fig. 6. Besides the implementation of the above algorithm, it enables recording (.txt format) and printing of the results. Because of relatively few inputs, to avoid unnecessary complexity, it provides input just manually, not from file.

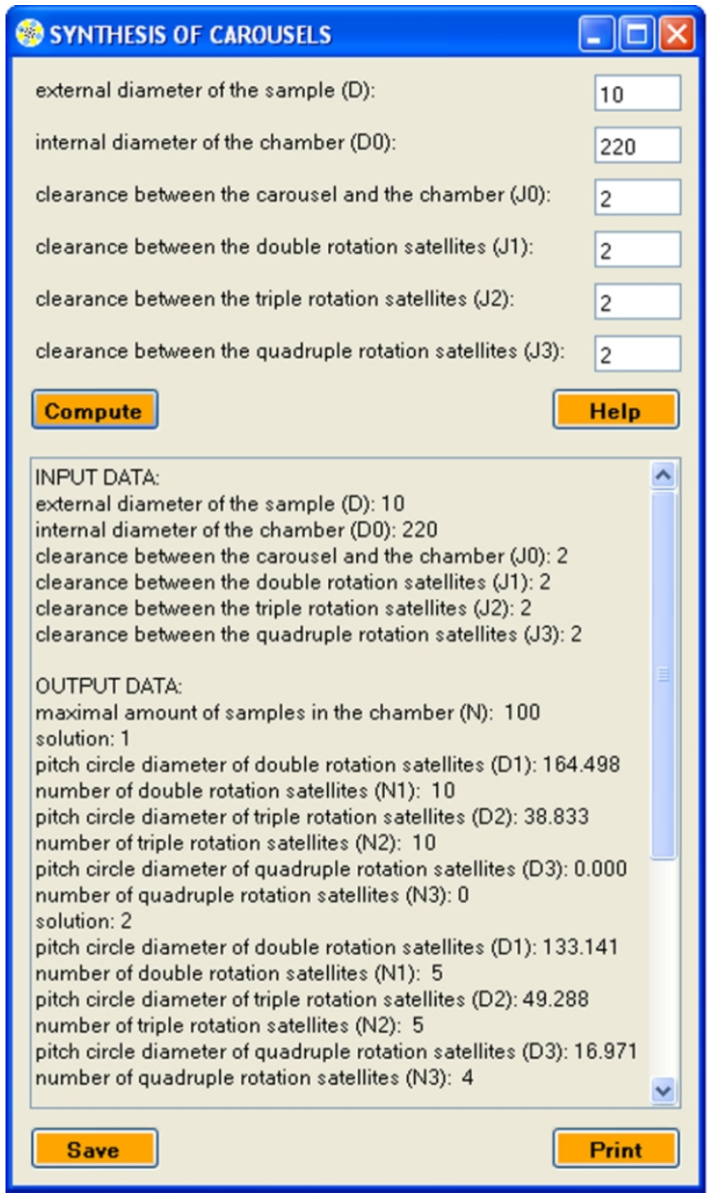

Fig. 6. The main window of the program.

The choice of Visual Basic is not accidental. Its version Visual Basic for Applications (VBA) is supported by many CAD programs – SolidWorks, AutoCAD, etc. So the created program can easily be transformed to a particular application for any of these products and further increase their functionality. But that would happen at the expense of the program's universality.

4 Results and Discussion

Four equivalent solutions proposed by the program are shown in Fig. 7 (the first two can be seen on the window in Fig. 6). All of them provide maximum collection of samples on one floor. The solution in Fig. 7a is the simplest to construct, it is a triple rotation carousel. However, it includes many double rotation satellites and therefore loading/unloading of the working chamber would be the slowest (assuming that double rotation satellites are placed sequentially). Other decisions have more complex structure, they are quadruple rotation carousels. The solution in Fig. 7d implies relatively large weight of the double rotation satellites, which would also be somewhat uncomfortable for loading/unloading. Perhaps the most successful solution is in Fig. 7b or Fig. 7c. However, the final choice will be made by the designer, with full information about the workflow.

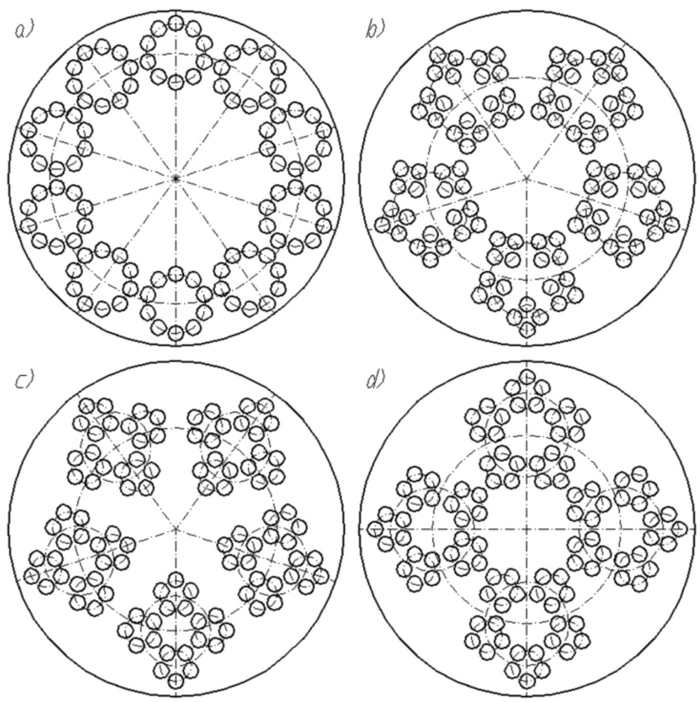

Fig. 7. Four possible solutions with D=10, D0=220, J0=J1=J2=J3=2. All of them offer N=100 (maximal amount of samples in the chamber).

It is well known that the transition to the carousels with more rotation axes increases deposition time [4], [10], [11]. The reason is that the surface of samples more seldom passes directly in front of the target, the so-called shadowing effect is exhibited. This increase in time is not great, especially relative to the duration of the entire working cycle. So, in general, is usually better to gather more samples, even slightly increasing the deposition time. Also, the number of rotation axes is associated with some other specific effects such as the modulation periods [2], [10], [11]. The program allows one to explore the best solutions in fewer axes of rotation. It is sufficiently to input very large values for the corresponding clearances - Fig. 8.

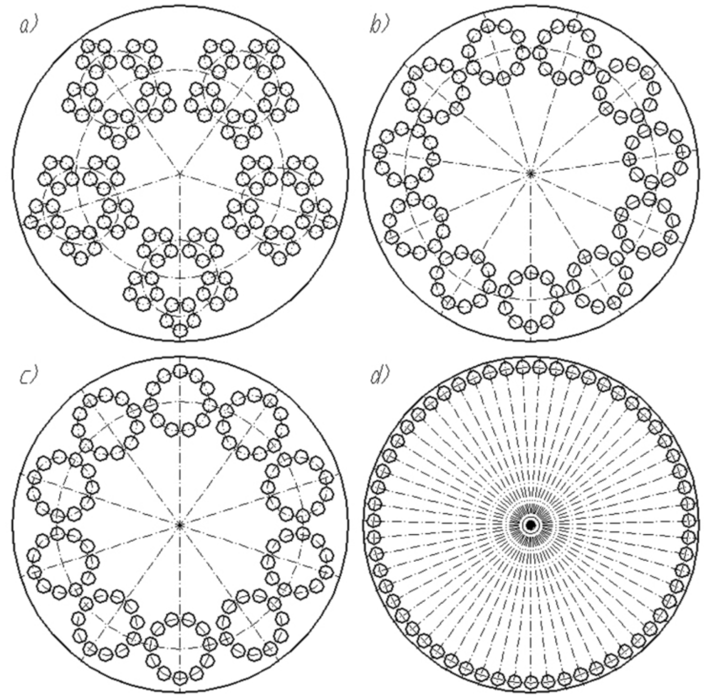

Fig. 8. The change of the maximal amount of samples in the chamber (N) with reduction of rotation axis: (a) D=9, D0=220, J0=J1=J2=J3=2 - quadruple rotation carousel with N=125 , (b) and (c) the same as primary but J3=220 – two solutions for triple rotation carousel with N=110 and (d) the same as primary but J2=J3=220 – double rotation carousel with N=59.

5 Conclusions and Future Works

The created program allows to reduce the design time of carousels for PVD technology dramatically. With its help a similar carousel (Fig. 9) has been implemented.

One of the possible developments of this program, as mentioned above, is one embedding in a suitable CAD environment. Since it does something very specific, this initiative will make sense if one expects extensive manufacturing of carousels. On the other hand, even in this current form, the program gives great relief of the construction work and it is universal, operating directly in the Windows environment. The author has not provided for integration of the program in a CAD environment yet.

Another possible development is addition of an algorithm for dealing with so-called interlaced carousels (Fig. 10). Under specific conditions, they allow one to collect more samples in the chamber, but they have many drawbacks. Some time ago, the author had to make a choice whether to construct simple or interlaced carousel that could collect the same amount of samples (on one floor). The choice fell on the simple carousel, although it would have more double rotation satellites, which generally increases the loading/unloading time.

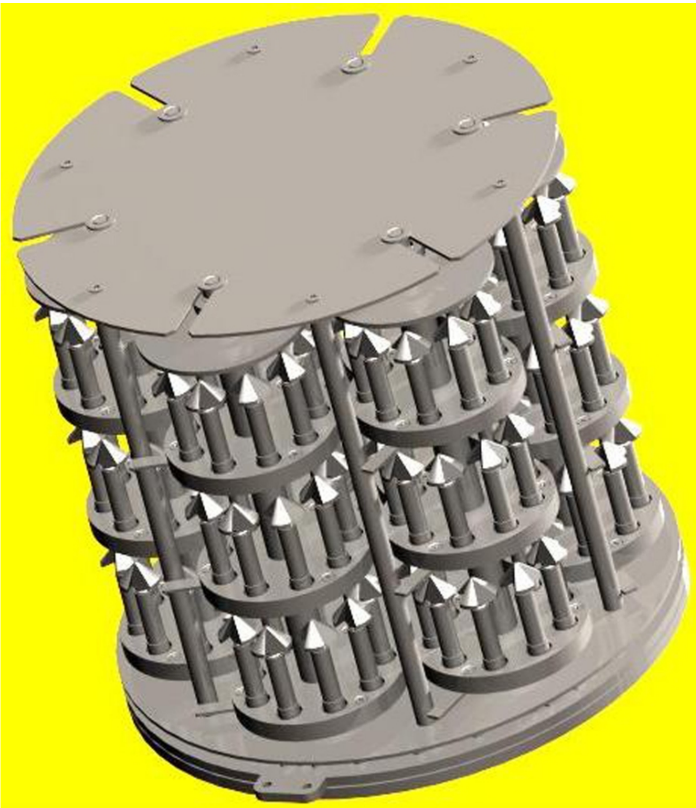

Fig. 9. Triple rotation carousel for samples transportation (here 162 countersinks).

The interlaced carousels necessarily require an even number of interlaced satellites and different direction of rotation for half of them. Moreover, their loading/unloading is associated with some difficulty because of their interlacing. In general, the carousel mechanics is also a bit more complicated. Although the author has an idea for an appropriate algorithm for their synthesis, he does not believe that there is a practical need for such realization at present.

The most probable development of the program is its use in combination with a model similar to that in [4], [10], [11]. Then man could select the most productive solutions in combination with the most appropriate structure of the coatings. This model will be particulary related to EAD, as far as this is the basic technology available to the author. To the best of his knowledge, such models still do not exist and it is challenge to create them.

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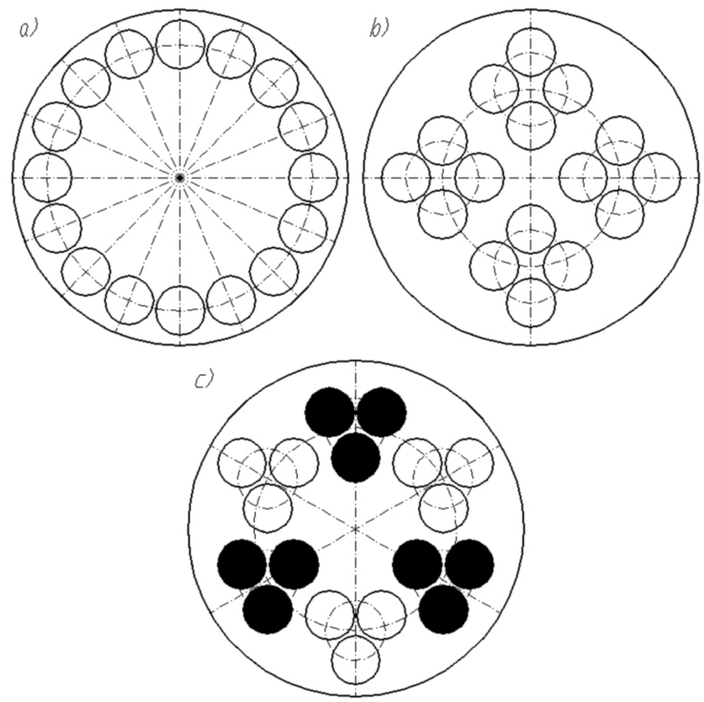

Fig. 10. Possible solutions with D=32, D0=220, J0=J1=J2=J3=2: (a) and (b) both program solutions with N=16 and (c) one interlaced triple rotation carousel with N=18 – the solid hatched satellites revolve in the opposite direction of the others.

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