Improving the Efficiency of "Jacketing" by Taking Into Account the Specifics of Applied Equipment and Prefabrications Based on Machine Learning Methods

Leonid Mylnikov
Department of Information Technologies and Automation Systems
Perm National Research Polytechnic University
Perm, Russia
leonid.mylnikov@pstu.ru

Artur Mikhailov
Microprocessor Automation Means Department
Perm National Research Polytechnic University
Perm, Russia
mihailovarthur@rambler.ru

Anatoliy Pesterev
Process Automation Department
Perm Scientific-Industrial Instrument Making Company
Perm, Russia
pesterev@ppk.perm.ru

Dmitrii Vershinin
Microprocessor Automation Means Department
Perm National Research Polytechnic University
Perm, Russia
nsenz@yandex.ru

Abstract—The article considers the task of choosing the optimal set of silica tubes for the operation of jacketing in the production of optical fiber, taking into account the available types of silica tubes, the features of the used equipment and the quality of products in previous cycles of production. The model, which allows considering the previous experience at a performance of the operation of a jacketing during the industrial process based on the decision of a problem of classification results. The model takes into account the physical features of the process and uses the results of technological operations for further refinement and correction. For primary education, the models used already available statistical data. Practical application of the model allows getting many possible solutions to the problem of selection of jacket tubes, which helps to reduce scrap in the jacketing.

Keywords—machine learning, optimization, binary classification, multi-class classification, np-complete, optical fiber, jacketing, jacket.

I. INTRODUCTION

These days optical fiber is being widely spread in various areas of human activities. The properties it possesses make possible to information transform at a high speed over large distances at a high-speed connection. Also, it's not susceptible to electromagnetic interference and corrosion resistant as well as any other damage to physical nature. To reduce the production cost of optic fiber "Jacketing" techniques are used. As a result, the core and the light-reflective surface surrounding it account for only 5-20% of the total volume due to adding an extra silica tube over the preform. The specifications and costs of these techniques depend on the number of the tubes used, the clearance between the preform and the tube and performance characteristics of the equipment in use. "Jacketing" has variability in selecting the types of tubes, which determines both the quality of the product and its cost. Variability is related to the types of tubes currently available and the features of the equipment used.

Jacketing was especially intensively developed in the 80-90s of the twentieth century [1]. Currently, the most popular fiber production methods are fiber optic production methods, the parameters of which allow to successfully scaling optical fiber, such as OVD, VAD [2]. However, in the tasks of precise adjustment of the output diameter of the workpiece to the requirements of the design documentation, the technology of jacketing has no analogs [3]. In the production of optical fibers, the optimum use of jacket tubes is a problem in jacketing (silica jacket tubes of different sizes). From formulation, the problem is similar to such classical problems as the backpack problem [4] and cutting problems [5]. Both tasks are NP-complete.

A solution of small dimensional problems is difficult due to the changing characteristics of the equipment (for example, as a result of wear and tear and scheduled maintenance) and properties of pipes, depending on their geometry, as well as the manufacturer and the quality of a particular batch. The need to take into account the physical properties of the waste process (reduction of the useful area of the tube) is another factor that complicates the task. Its size depends on the modes and type of equipment used, as well as the type of tube used.

Machine learning methods are used to take into account the peculiarities of operation and dynamics of changes in equipment properties [6]. These methods use statistical data based on empirical models. To solve the problems of choosing the type of tube for building, based on the possibilities of changing its transverse dimensions, binary [7] and multi-class classification problems [8] can be considered.

II. PROCESS DESCRIPTION

The optical fiber manufacturing process consists of several stages: the core production stage and the entrainment stage of the protective shell. Then this work piece is resizing into the optical fiber. With only one work piece, the length of such optical fiber reaches hundreds and thousands of meters.

Jacketing is the result of inserting the core into the silica tube and heating it (up to ~2000 °C), which results in compression to the core diameter due to surface tension forces. Then the process repeats until the target diameter is reached. The absolute dimensions of the core and reflective jacket in the original and "jacketed" workpieces remain the same, and only the ratio of workpiece diameters to the core changes.

Jacketing requires the use of quartz pipes with different outer and inner diameters. Silica tubes are melted in the process of jacketing and their outer and inner diameters change. The type of tube used and the features of the equipment used for the process, which will determine the parameters that characterize the physical properties of the process, determine the possibilities of changing these diameters. The magnitude of the change in the ranges of these values can be quite large (Figure 1 shows the points corresponding to the successful performance of the jacketing operation). It can be seen that as the dimmer increases, the stretching of the jacket tube decreases. The opposite pattern would mean that the data is incorrect. Also, some erroneous measurements can be noticed which are out of line (e.g. when a Type 2 tube is stretched more strongly than a Type 5 tube).

The graph shows that when the dimmer is increased, the value of the jacket tube is reduced to which it is stretched. This is because the cross-sectional area of the tube (CSA_{tube}) cannot be increased. However, it may decrease due to waste, the volume of which depends on the peculiarities of the process and equipment (CSA_{waste}).
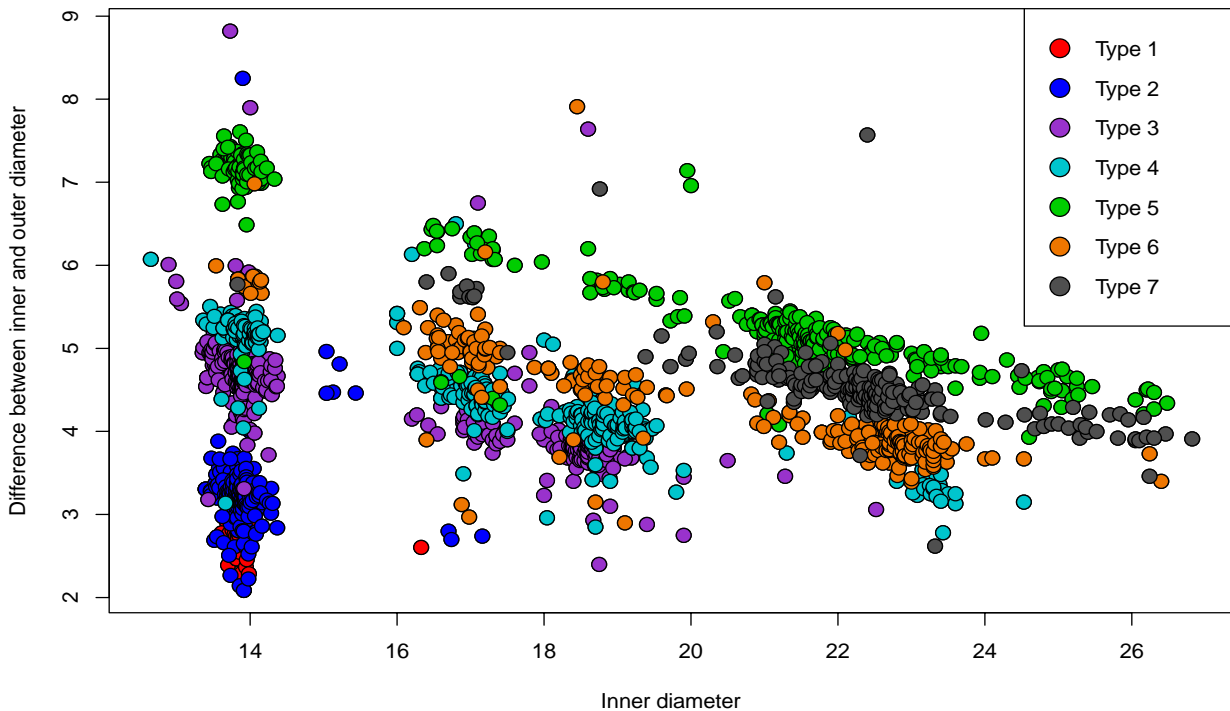

Fig. 1. Statistical data on the use of different types of silica tubes on one of the machines (Type 1 - 20x1.3x1000 silica tube, Type 2 - 20x1.5x1000 silica tube, Type 3 - 23x2x1000 silica tube, Type 4 - 25x2x1000 silica tube, Type 5 - 25x3x1000 silica tube, Type 6 - 28x2x1000 silica tube, Type 7 - 32x2x1000 silica tube)

III. PROBLEM-SOLVING METHODOLOGY

The task of management is to minimize the number of tubes used, provided that there is no scrap. It can be assumed that the solution is not the only one since the problem includes large changes in the internal and external diameters for each type of tube. The task can be considered as recurrent since for the case of n partitions (see Fig. 2) it can be solved through the solution of the task for (n-1) partitioning.

Let us consider the problem in general. Suppose n – the number of breaks, m - the number of tube types, S_n – a lot of possible solutions for n breaks, R_1– a smaller diameter, R_2 R_2 – a larger diameter, $F_0(R_1, R_2, m)$ – a function returning TRUE if the tube type m can accept a given geometry. Then it is possible to write the algorithm for $n = 0$, which is shown in Fig. 2 a). If this algorithm is designated through the $F_0(R_1, R_2, m)$, the algorithm can be obtained for the case with one joint (see Fig. 3a and Fig. 3b) and extended to the following cases.
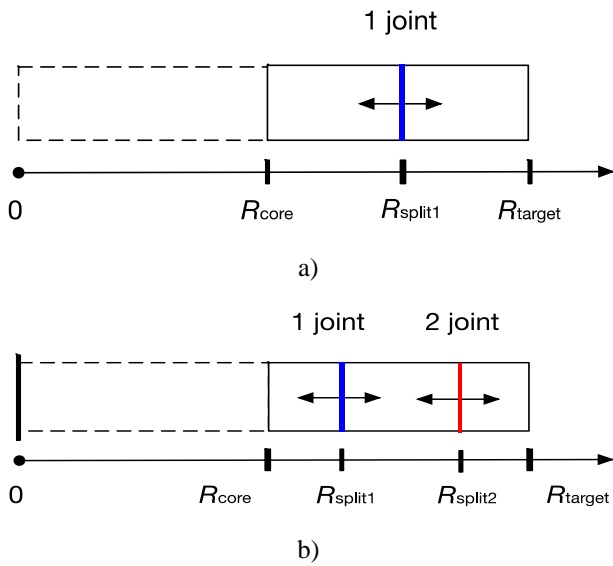
a)

b)

Fig. 2. Illustration of the required workpiece radius, a) when using 2 pipes, b) when using 3 pipes
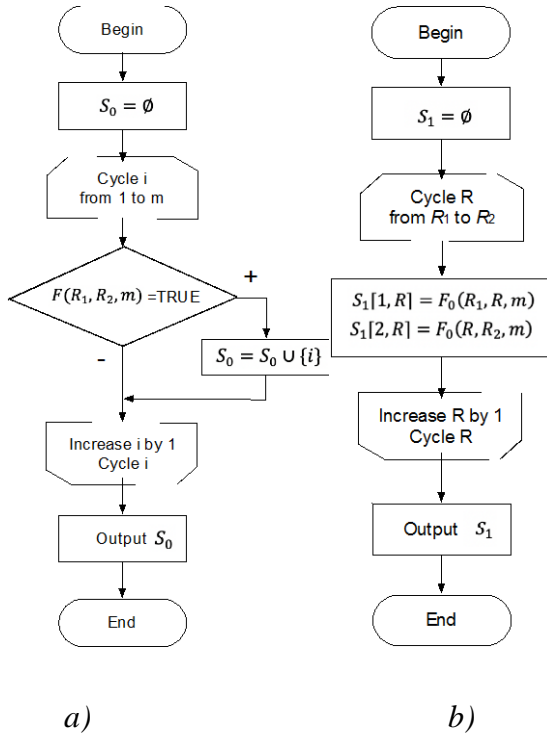

a)   *b)*

Fig. 3. Tube selection algorithms for cases: a) $n=0$, b) $n=1$

As a result of the solution of the problem, there will be a set of possible solutions, the elements of which are related sets corresponding to different combinations of sections (joints of tubes). The search for a solution is described by the recurrence ratio (1) and (2):

$$S_0 = F(R_1, R_2, m) \qquad (1)$$

$$S_n = F_{n-1}(R_1, R, m) \oplus F(R, R_2, m) \qquad (2)$$

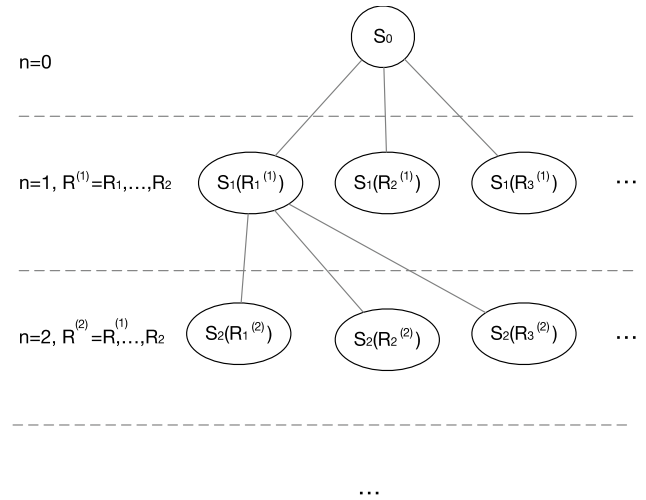The set of solutions obtained will be a tree, shown in Fig. 4.

Fig. 4. Structure of formation of a set of possible decisions

To implement the above approach, it is necessary to implement the function $F(R_1, R_2, m)$ taking into account the value of waste material of tubes. Having statistical data (See Fig. 3), this problem can be solved as a classification problem [9] based on machine learning methods.

To select the model, the entire data set was divided into two parts: training (70% of the total) and test (30% of the total). Then the classification model was built based on the knn, svmLinear3, neural network, pls, random forest, naive Bayes, AdaBoost (from the caret library of the R language [9]) for each of the tube types. Before dividing the data, mix them in such a way that the distribution of statistical data in the test and training samples by tube type is in the same proportions (it is necessary because the amount of data on different types of tubes was different, and their application was not evenly distributed over time). Accuracy [10] obtained from the test sample using different models of machine learning is shown in Table 1.

TABLE I.   ACCURACY FOR EACH MACHINE LEARNING MODEL CONSIDERED

Class	Method					
	knn	svmLinear3	nnet	pls	random forest	AdaBoost
Type 1	**0.9873418**	0.01265823	0.9859353	0.9817159	0.01828411	0.9817159
Type 2	**0.9817159**	0.01828411	0.9760900	0.8818565	0.11814346	0.8818565
Type 3	**0.9549930**	0.22784810	0.9437412	0.7721519	0.22784810	0.7721519
Type 4	**0.9493671**	0.05063291	0.9184248	0.8087201	0.19127989	0.8087201
Type 5	**0.9789030**	0.02109705	0.9746835	0.8255977	0.17440225	0.8255977
Type 6	**0.9746835**	0.02531646	0.9029536	0.8607595	0.13924051	0.8607595
Type 7	**0.9774965**	0.02250352	0.9296765	0.8691983	0.13080169	0.8691983
Total	**0,972071543**	**0,054048626**	**0,947357843**	**0,857142843**	**0,142857144**	**0,857142843**

The use of one of the machine learning models to solve the problem of classification allows determining the ranges of diameter changes in the process of workpiece processing for different types of work and different technological installations. This allows you to implement the function $F(R_1, R_2, m)$.

The choice of algorithm is based on metrics (Table 1). Those metrics show the accuracy of the range of internal and external diameter changes based on the type of tube. As can be seen, the best result was shown by the kNN model (the model shows the best result in the application of other metrics as well), and the learning rate was the fastest.

The peculiarity of the use of machine learning models to solve the problem of classification is the possibility of adding new data to the training sample and retraining of the model, which leads to increased accuracy of the model.

IV. SOLUTION

Implementation of the function $F(R_1, R_2, m)$ allows you to write the algorithm of solving the task based on the recursive call, see Fig. 5.

Step 1. The operator provides input and expected output;
Step 2. The algorithm searches for all possible outputs for the original input when using all types of tubes through the recursive $F(R_1, R_2, m)$ function call, and then sift out the invalid answers using the CSA of the tubes used as restrictions;
Step 3. If there is an answer in which the minimum possible output is greater than or equal to the desired one (specified by the operator), proceed to step 4, otherwise perform the next iteration (return to step 2);
Step 4. Output the found solutions.

Fig. 5. Algorithm for searching for tube sets to reach a given outer diameter

As a result of its application on the available data, we will receive sets of possible combinations of pipes leading to the set target value of external diameter taking into account possible deviations at the use of the chosen pipes on the equipment for which the statistics were collected (see examples in Tables 2-4).

Now the decision of a problem of a choice of the sequence of tubes leans on the expert opinion of the technologist and empirically picked up factors that have allowed to develop experimentally a sequence of use of types of jacket tubes. The analysis of the results obtained by the algorithm allows demonstrating the successful implementation of the solutions and their compliance with the requirements of the equipment. The peculiarity of the received solution is that in contrast to the currently used schemes of expansion the algorithm can be trained for any type of tubes. At the stage of analysis, solutions were proposed, that were not used earlier in the production process. This algorithm has the option to recalculate the options for further increase in the case of incorrectly executed technological operation or lack of the necessary type of tubes in the warehouse, and thus exclude the occurrence of defects or unfinished products.

V. CONCLUSION

The algorithm given in the article describes a way to solve the problem of selection of jacket tubes to increase the diameter of the optical fiber blank, taking into account the specifics of equipment and materials used based on statistical data collected. Further research is planned to be linked to the determination of the adaptivity rate of the obtained algorithm, as well as to the determination of the required amount of previous data to ensure the required adaptivity. This may further increase the effectiveness of this approach.

TABLE II.   OPTIONS FOR INCREASING THE OUTER DIAMETER FROM 14.2 TO 17.3 MM WITH ONE TUBE

№	Type of 1st tube	Diameter after the 1st tube (mm)
1	23x2x1000	[18.2981 : 18.5171]
2	25x2x1000	[18.7361 : 19.1011]

TABLE III.   COMBINATIONS TO INCREASE THE OUTER DIAMETER FROM 14.2 TO 22.3 MM WITH TWO TUBES

№	Type of 1st tube	Type of 2nd tube	Diameter after the 1st tube (mm)	Diameter after the 2nd tube (mm)
1	20x1.5x1000	25x3x1000	[16.7651 : 17.0571]	[23.0721 : 23.6561]
2	20x1.5x1000	32x2x1000	[16.7651 : 17.0571]	[22.6341 : 22.9261]
3	23x2x1000	23x2x1000	[18.2981 : 18.5171]	[22.2691 : 22.4881]
4	23x2x1000	25x3x1000	[18.2981 : 18.5171]	[24.2401 : 24.8971]
5	23x2x1000	28x2x1000	[18.2981 : 18.5171]	[23.5831 : 23.6561]
6	25x2x1000	23x2x1000	[18.7361 : 18.9551]	[22.6341 : 22.7801]
7	25x2x1000	25x3x1000	[18.7361 : 19.1011]	[24.6781 : 25.3351]
8	25x2x1000	28x2x1000	[18.7361 : 19.1011]	[23.4371 : 24.0941]
9	25x3x1000	25x3x1000	[20.7071 : 21.2181]	[26.1381 : 26.9411]
10	25x3x1000	32x2x1000	[20.7071 : 21.2181]	[25.7001 : 26.1381]
11	25x3x1000	28x2x1000	[20.7071 : 21.2181]	[25.1161 : 25.4081]

TABLE IV.   COMBINATIONS TO INCREASE THE OUTER DIAMETER FROM 14.2 TO 28.4 MM WITH THREE TUBES

№	Type of 1st tube	Type of 2nd tube	Type of 3rd tube	Diameter after the 1st tube (mm)	Diameter after the 2nd tube (mm)	Diameter after the 3rd tube (mm)
1	20x1.5x1000	25x3x1000	25x3x1000	[17.587 : 17.806]	[23.675 : 24.332]	[28.522 : 29.471]
2	23x2x1000	25x3x1000	25x3x1000	[19.047 : 19.12]	[24.843 : 25.281]	[29.471 : 30.201]
3	23x2x1000	25x3x1000	32x2x1000	[19.047 : 19.12]	[24.843 : 25.281]	[29.106 : 29.544]
4	23x2x1000	28x2x1000	25x3x1000	[19.047 : 19.12]	[23.675 : 24.113]	[28.522 : 29.252]
5	25x2x1000	25x2x1000	25x3x1000	[19.412 : 19.704]	[23.529 : 23.967]	[28.376 : 29.179]
6	25x2x1000	25x3x1000	25x3x1000	[19.412 : 19.704]	[25.062 : 25.792]	[29.69 : 30.639]
7	25x2x1000	25x3x1000	32x2x1000	[19.412 : 19.704]	[25.062 : 25.792]	[29.325 : 30.201]
8	25x2x1000	28x2x1000	25x3x1000	[19.412 : 19.631]	[24.04 : 24.259]	[28.814 : 29.398]
9	25x2x1000	32x2x1000	25x3x1000	[19.412 : 19.631]	[24.77 : 24.77]	[29.471 : 29.836]
10	25x2x1000	32x2x1000	32x2x1000	[19.412 : 19.631]	[24.77 : 24.77]	[29.033 : 29.033]
11	25x3x1000	25x3x1000	25x3x1000	[21.31 : 21.821]	[26.595 : 27.398]	[31.004 : 32.026]
12	25x3x1000	25x3x1000	32x2x1000	[21.31 : 21.821]	[26.595 : 27.106]	[30.639 : 31.223]
13	25x3x1000	32x2x1000	25x3x1000	[21.31 : 21.748]	[26.157 : 26.595]	[30.639 : 31.369]
14	25x3x1000	32x2x1000	32x2x1000	[21.31 : 21.748]	[26.157 : 26.595]	[30.274 : 30.785]
15	25x3x1000	28x2x1000	25x3x1000	[21.529 : 21.821]	[25.719 : 26.084]	[30.274 : 30.931]
16	25x3x1000	28x2x1000	32x2x1000	[21.529 : 21.821]	[25.719 : 26.084]	[29.836 : 30.274]
17	28x2x1000	25x2x1000	25x3x1000	[19.996 : 20.142]	[24.04 : 24.186]	[28.814 : 29.325]
18	28x2x1000	25x3x1000	25x3x1000	[19.996 : 20.434]	[25.573 : 26.303]	[30.128 : 31.077]
19	28x2x1000	25x3x1000	32x2x1000	[19.996 : 20.434]	[25.573 : 26.303]	[29.763 : 30.493]
20	28x2x1000	32x2x1000	25x3x1000	[20.142 : 20.434]	[25.208 : 25.573]	[29.836 : 30.493]
21	28x2x1000	32x2x1000	32x2x1000	[20.142 : 20.434]	[25.208 : 25.573]	[29.398 : 29.909]

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