The applicability of existing renovation methods in technology of screw compressors repairing

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Abstract. The article deals with the basic methods of machine parts recovery. Advantages and disadvantages of these methods had been widely spoken. The effect of these methods on the surface properties had been analysed. The main reasons of the wear of screw compressor parts are described in short. The authors paid attention to the evaluation of the applicability of existing renovation methods in technology of screw compressors repairing. In choosing the optimal method of renovation the surfaces of screw compressor parts are guided by the criteria of RAMS: reliability, availability, maintainability and safety. Also, it is specially noted about the evaluation of the effect of renovation methods on the screw surface layer by the following criteria: adhesion, ecological safety, cost, wear resistance, hardness, roughness, layer thickness, capacity, hogging, porosity, surface preparation, changes in the structure and physical properties of the base metal and ease of use. The most appropriate method for the renovation of parts of screw compressors had been proposed.

1. Introduction
A screw compressor is a type of compressor that uses a rotary-type positive-displacement mechanism. They are commonly used to replace piston compressors where large volumes of high-pressure air are needed, either for large industrial applications or to operate high-power air tools such as jackhammers.

Screw compressors don’t have any assembly units that perform reciprocating movements. Therefore, there are no alternating loads on parts and the increased wear of friction responsible pairs. That’s why the life cycle of screw compressors is long. Fulfilling the requirements of exploitation can increase their life cycle up to 40 000 hours. The units, limiting resource of screw compressors, are bearings, installed on drive and driven shafts. In addition, the abuse could lead to mechanical damage of the screw’s guide.

2. Formulation of the Problem
If there is continued operation of compressor with the hot oil, if the frequent starting and stopping of the compressor is made, bearings can become damaged prematurely. This situation can lead to the failure of the compressor, related to the jamming of the screws, prehension of screws and the compressor’s housing. The repair of such compressor can be pursuance only in plant conditions, but in a number of cases the compressor unit must be changed. Basically, there are following types of wear during the screw compressors operation: wear of bearings’ seats and wear of the working surfaces of screws (Figure 1).
Generally, the wear rate is not over than 0.3 mm in diameter, but it can lead to reduce the capacity of the compressor, because the initial clearance between screws is 0.05 mm. To prevent such situations, it needs to make a diagnostic review of bearings with special handheld devices. This reliable equipment is readily available. It should be included to the list of necessary repairing tools for maintenance services of the plants, where the screw compressors are being used. This notwithstanding the damaged screws usually must be replaced with new ones.

![Figure 1. Places of screw’s wear: 1 - working surfaces of screws; 2 - bearings’ seats.](image)

Therefore, it is considerably expensive from an economic standpoint. Hence, the main aim of the study is to find the most effective method of renovation of worn screw surfaces and bearings’ seats.

3. Findings of Investigation
Most methods of recovery should be considered as an alternative. The same coating material can be applied in several ways. In this case, the properties of the coating layer and cost of its application can vary significantly. The application conditions can change the mechanical properties of the base material. In this way, the properties of the coated part depend on the method of application. To renovate the worn part means to restore the primary (or close to them) geometric, physical, mechanical, chemical and other properties, to eliminate operational defects, to restore dimensions and geometric shape according to technical requirements. According to [1], the operability and resource of the renovated parts averages by 60...80% of these indicators for new parts. However, at present there are some technological methods which can completely restore the original resource of parts or even increase it. Restoring of the parts allows saving a significant amount of materials. Also, it leads to noticeably extend the life cycle of the parts and reduce the cost of equipment repair. Currently, there are many different technological methods to compensate the worn-out layer of parts [1 - 4]. The most common methods, their advantages and disadvantages are shown in Table 1.

Analysing the data of Table 1, we can conclude that each of these methods has its advantages and disadvantages. But to select the recovery method for a narrower application (namely, for renovation of the surfaces of the screws and seats for the bearings of screw compressor units), several criteria must be taken into account. There are the following criteria to selecting the optimal method of restoring parts: applicability, durability and economic [5].

The criterion of applicability determines the fundamental possibility of applying various recovery methods for specific details. This criterion is described by the function:**
\[ K_D = \varphi(M_D; \Phi_D; D_D; C_D; H_D; \sum_{i=1}^{m} T_i) \]  

where:
- \( M_D \) – the material of the part;
- \( \Phi_D \) – the shape of the surface to be restored;
- \( D_D \) – the diameter of the surface to be restored;
- \( C_D \) – the wear of the part;
- \( H_D \) – the load acting on the part;
- \( \sum_{i=1}^{m} T_i \) – the sum of technological features of the method that determine the area of its rational application.

**Table 1. Methods for repairing worn surfaces.**

| Method                | Advantages                                                                 | Disadvantages                                                                 |
|-----------------------|----------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Surfacing             | Increasing hardness and wear resistance, the possibility of unlimitedly increasing the worn surface | The formation of cracks, high porosity, the presence of slag inclusions, reduced fatigue strength, warpage, increased environmental hazard |
| Electroplating        | Preserves the structure of the part, high wear resistance and hardness of the surface | Low run-in, reduced fatigue strength, low adhesion, increased environmental hazard |
| Metallization         | The mechanical properties of the material do not change, the part is not subjected to buckling, high wear resistance | High porosity (up to 10%), reduced fatigue strength, low adhesion, increased environmental hazard |
| Plastic deformation   | Increases hardness, reduces roughness, increases wear resistance | Low productivity, it is possible to deform the surface by 5-10 microns or more |
| Electroerosion allying| Local surface treatment; a strong compound of the transferred and base metal; absence of general heating of the part during processing, possibility of using as processed materials: pure metals, alloys, metal-ceramic compositions, refractory compounds; increase hardness, heat resistance, wear resistance and corrosion resistance; no need for surface preparation | Appearance of tensile residual stresses in the surface layer, reduction of fatigue strength, roughness increase |
| Application of polymer materials | The ability to unlimitedly increase the worn surface, close to metal deformation characteristics, high adhesion | The need for special surface preparation, including the formation of surface roughness. Relatively low hardness |

By this criterion competitive methods are selected for further evaluation by other criteria.

The criterion of durability determines the operability of the parts being restored. It is expressed by the coefficient of durability, which is meant the ratio of the durability of the restored part to the durability of the new one. This criterion is described by the function:

\[ K_D = f_1(k_C; k_B; K_{Dy}) \]
where:

- $k_c$ – coefficient of stability against wear;
- $k_B$ – coefficient of endurance;
- $K_\sigma$ – adhesion coefficient.

The economic criterion is the function of two arguments:

$$K_{m,e} = f_2(k_{np}; e)$$  (3)

where:

- $k_{np}$ – coefficient of productivity of the method;
- $e$ – an indicator of the economy of the method.

The economic effect of the introduction of the developed technological process of the restoration is determined by the formula:

$$e = \left[ \frac{C_B^{m(\delta)}}{C_B^{m(i)}} - E_n(k_i - k_0) \right] N_B$$  (4)

where:

- $C_B^{m(\delta)}$ – the full cost price of restoration with a base variant of technological process;
- $C_B^{m(i)}$ – the full cost price of restoration with i-th (introduced) technological process;
- $E_n$ – normative coefficient of investment efficiency ($E_n=0.15$);
- $k_i$, $k_0$ – capital investments in accordance with the introduced and basic technological processes (equipment, instrument, design, manufacturing, on-site installation, etc.);
- $N_B$ – the program of restoration of details.

The payback period after the introduced technological process is determined by the formula:

$$\tau_{ok} = \frac{\Delta K}{(C_B^{\delta(i)} - C_B^{\delta(i)}) N_B}$$  (5)

where:

- $\Delta K = k_i - k_0$ – additional investment.

Determining the labour productivity, the process of restoring parts involves preparing the part, applying the material to the prepared part and processing it had been taken into account. Therefore, the recovery method and the process of applying the material by this method are evaluated separately by the productivity.

To visualize the objective evaluation of recovery methods for a particular application, consider Table 2.

### 4. Conclusion

- For the renovation of screw compressor parts, it is suggested to use combined methods.
- To use combined method consisting of ion nitriding with subsequent cementation by electroerosion alloying for the renovation of the bearings’ seats is insistently recommended.
- For the renovation of worn-out surfaces of screws the authors also insisted on using a combined method consisting of electroerosive alloying of the surface with an electrode made of corrosion-resistant steel with subsequent application of polymeric materials.
### Table 2. Evaluation of the criteria of recovery methods for renovation of the surfaces of screws and bearings’ seats for the of screw compressor units.

| Method                          | Adhesion | Environmental safety | Cost price | Wear resistance | Hardness | Roughness | Layer thickness | Productivity | Warping | Porosity | Surface preparation | Changes in the structure and physical properties of the base metal | Ease of application | Average score |
|--------------------------------|----------|----------------------|------------|-----------------|----------|-----------|-----------------|---------------|---------|----------|---------------------|---------------------------------------------------------------|------------------|---------------|
| Surfacing                      | 4        | 1                    | 2          | 4               | 5        | 2         | 3               | 4             | 2       | 2        | 4                   | 2                                                             | 3                | 2.9           |
| Electroplating                 | 2        | 1                    | 1          | 4               | 4        | 3         | 2               | 2             | 3       | 4        | 1                   | 4                                                             | 2                | 2.5           |
| Metallization                  | 2        | 1                    | 2          | 4               | 4        | 2         | 2               | 3             | 4       | 1        | 2                   | 4                                                             | 2                | 2.5           |
| Electroerosion alloying        | 5        | 3                    | 4          | 4               | 2        | 2         | 4               | 4             | 3       | 4        | 3                   | 5                                                             | 4                | 3.9           |
| Application of polymer materials | 4     | 4                    | 3          | 3               | 1        | 3         | 5               | 5             | 5       | 5        | 1                   | 5                                                             | 5                | 3.8           |
| Combined method 1<sup>a</sup>  | 5        | 4                    | 4          | 5               | 4        | 4         | 5               | 5             | 4       | 4        | 4                   | 5                                                             | 4                | 4.5           |
| Combined method 2<sup>b</sup>  | 5        | 4                    | 4          | 5               | 5        | 5         | 4               | 4             | 4       | 5        | 4                   | 5                                                             | 5                | 4.6           |

<sup>a</sup> Method for the restoration of bearings’ seats, consisting of ion nitriding with subsequent cementation by electroerosion alloying.

<sup>b</sup> Method for the restoration of worn out surfaces of screws, consisting of electroerosive alloying of the surface with an electrode made of corrosion-resistant steel with subsequent application of polymeric materials.

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