УДК 621.03.004.74:621.03.004.67 – 167.7

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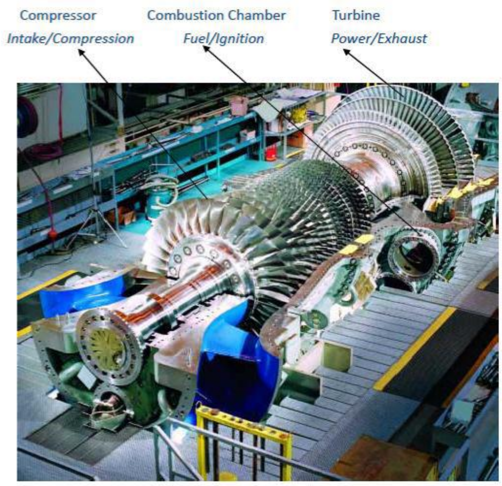
SAVING DISASSEMBLY AT HEAVY-DUTY GAS TURBINE COMPRESSOR REENGINEERING

In a paper the considered questions of a machine industry hard loaded responsible products resource saving at a stage of their repair, on an example of the heavy-duty gas-turbine compressors. The main causes of failure and include the results of turbo systems. The modern concept of the rational search path to the failed element of sophisticated equipment. The technique of safe disassembly of their element base in view of maintenance specificity conditions of and residual influence on an environment is stated. Practical application of the offered approach will allow to increase quality and safety of special assignment, and introduction of the formalized technique in conditions of real manufacture will allow increase in level of efficiency and the use of available means of complex technological equipment.

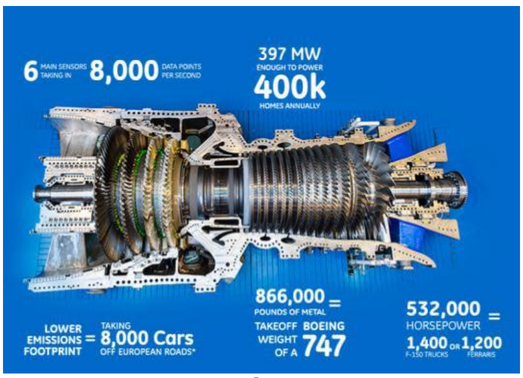
Keywords: repair, selective disassembly**,** heavy-duty compressors, gas-turbine, resource saving.

INTRODUCTION

In modern manufacture, in many areas of the industry heavy-duty gas turbine have found application (Figure 1)[16].



a



b

Fig.1 - Heavy-duty gas turbine:
a – typical construction; b – heavy-duty parameters

Distinctive feature of such equipment is:

- the big size;
- the big weight;
- high cost of components;
- increased requirements to manufacture, maintenance and repair of the equipment.

Maintenance costs and machine availability are two of the most important concerns to a heavy-duty gas turbine equipment owner. Therefore, a well thought out maintenance program that reduces the owner's costs while increasing equipment availability should be instituted. General Electric (GE) have Gas turbine maintenance program. For this maintenance program to be effective, owners should develop a general understanding of the relationship between the operating plans and priorities for the plant, the skill level of operating and maintenance personnel, and all equipment manufacturer's recommendations regarding the number and types of inspections, spare parts planning, and other major factors affecting component life and proper operation of the equipment.

Advanced planning for maintenance is necessary for utility, industrial, independent power, and cogeneration plant operators in order to maintain reliability and availability. The correct implementation of planned maintenance and inspection provides direct benefits in the avoidance of forced outages, unscheduled repairs, and downtime. The primary factors that affect the maintenance planning process are shown in Figure 2. The owners' operating mode and practices will determine how each factor is weighted. Gas turbine parts requiring the most careful attention are those associated with the combustion process, together with those exposed to the hot gases discharged from the combustion system. These are called the combustion section and hot gas path parts, and they include combustion liners, end caps, fuel nozzle assemblies, crossfire tubes, transition pieces, turbine nozzles, turbine stationary shrouds, and turbine buckets.

Gas turbines wear differently in continuous duty application and cyclic duty application, as shown in Figure 3.

Fig.2 - Key factors affecting maintenance planning

- **Continuous Duty Application**
  - Rupture
  - Creep Deflection
  - Corrosion
  - Oxidation
  - Erosion
  - High-Cycle Fatigue
  - Rubs/Wear
  - Foreign Object Damage
- **Cyclic Duty Application**
  - Thermal Mechanical Fatigue
  - High-Cycle Fatigue
  - Rubs/Wear
  - Foreign Object Damage

Fig.3 - Causes of wear – hot gas path components

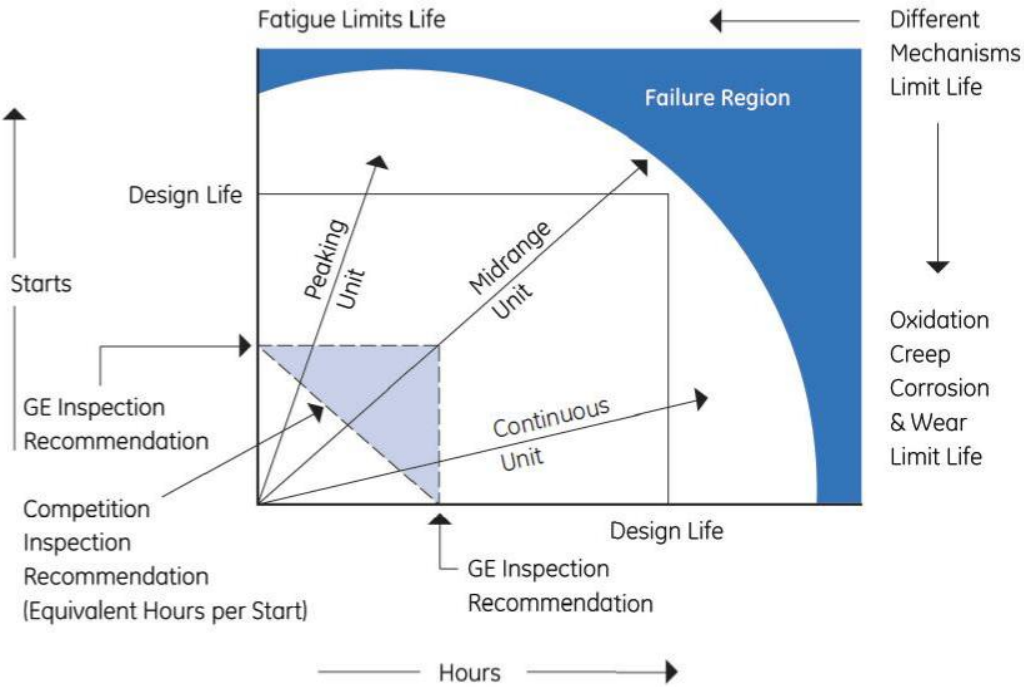


Fig. 4 - GE bases gas turbine maintenance requirements on independent counts of starts and hours

Thermal mechanical fatigue is the dominant life limiter for peaking machines, while creep, oxidation, and corrosion are the dominant life limiters for continuous duty machines. Interactions of these mechanisms are considered in the GE design criteria but to a great extent are second-order effects. For that reason, GE bases gas turbine maintenance requirements on independent counts of starts and hours. Whichever criteria limit is first reached determines the maintenance interval. A graphical display of the GE approach is shown in Figure 4. In this figure, the inspection interval recommendation is defined by the rectangle established by the starts and hours criteria. These recommendations for inspection fall within the design life expectations and are selected such that components acceptable for continued use at the inspection point will have low risk of failure during the subsequent operating interval.

STATEMENT OF THE PROBLEM

At a stage of gas turbine maintenance and repair there is their necessity for disassembly for access to the failed detail or a unit. It is known, that full disassembly of the equipment at repair – one of undesirable operations as even at the most qualified safe disassembly interface of the worn-in details and a normal tightness in slots with motionless landings are disturbed. The part of details at disassembly is damaged (inflow, paws, flanges break, edges of bolts, nuts get off, rivets and etc.). Aggregates and the details which are not demanding repair, at all it is not recommended to remove from the equipment because of possible lowering working capacity of machines as a whole. Therefore before disassembly of the equipment it is important to define objective necessity of execution of operations.

Modern direction in disassembly is Disassembly Wave Propagation (**DWP**) method [5,8,10,13]. The disassembly analysis involves evaluating a disassembly sequence (order of component removals) from the geometric model of an assembly (**A**). In general, two categories of problems exist in disassembly: (let $\mathbf{C_i}$ denotes the i[st] component in **A**)

1. *Complete Disassembly* (**CD**) involves disassembling all the components in **A** to obtain a **CD** sequence. For example, to disassemble all the components from **A** in Figure 5, one possible

sequence is {$\mathbf{C_1}$, $\mathbf{C_2}$, $\mathbf{C_6}$, $\mathbf{C_3}$, $\mathbf{C_4}$, $\mathbf{C_5}$}, as shown in Figure 6.

2. *Selective Disassembly* (**SD**) involves disassembling a subset of components (**C**) from **A** to

obtain a **SD** sequence (**S**). For example, to disassemble **C** = {$\mathbf{C_4}$, $\mathbf{C_5}$} for **A** in Figure 5, one

possible sequence **S** = {$\mathbf{C_6}$, $\mathbf{C_4}$, $\mathbf{C_5}$}, as shown in Figure 7.

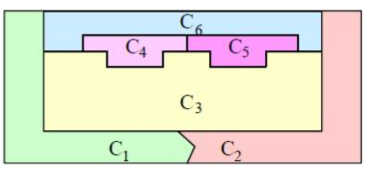


Fig.5 - Test assembly to illustrate complete and selective disassembly

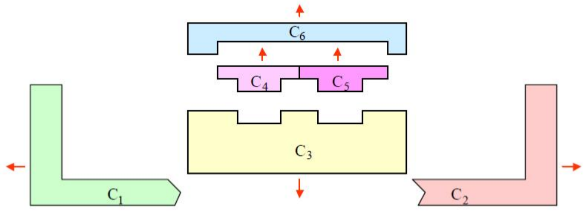


Fig.6 - CD sequence is {C_1, C_2, C_6, C_3, C_4, C_5} for A in Figure 5

An application for **CD** is assembling, since reversing a disassembly sequence can potentially yield to an assembly sequence. For example, in Figure 6 the reverse of disassembly sequence gives an assembly sequence {$\mathbf{C_5}$, $\mathbf{C_4}$, $\mathbf{C_3}$, $\mathbf{C_6}$, $\mathbf{C_2}$, $\mathbf{C_1}$}. However, **SD** is often more relevant than **CD** for applications such as maintenance, recycling and reuse. These applications usually require removal of a subset of components of **A**, and not the entire assembly, hence providing a need for **SD**.

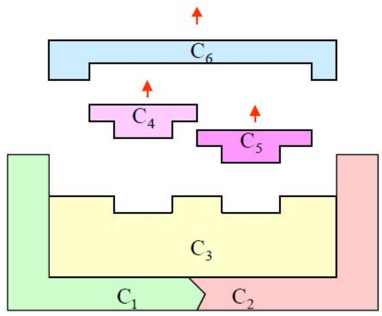


Fig. 7 - SD Sequence S = {C6, C4, C5} for C = {C4, C5} in Figure 5

In real conditions at repair gas turbine compressor needs multiple **SD** [1,4,14,17,18]. The multiple **SD** problem is formulated as follows: Given an assembly (**A)** of **n** components and target components (**C)**, automatically determine a **SD** sequence (**S**) for **m** < **n** components, where **m** = Cardinality (**C**).

One potential approach to perform the multiple **SD** analysis is by applying the **SWP** algorithm for every component in **C**. Although this approach may determine **S** for individual target components with a few removals, the resultant **S** for **C** (which is an aggregation of all sequences for $\mathbf{C_x} \in \mathbf{C}$) is not necessarily an appropriate **SD** sequence with fewer removals. To illustrate the multiple-component **SD** problem, consider **A** in Figure 8 with the requirement to disassemble **C** = {$\mathbf{C_3}$, $\mathbf{C_5}$}. Let $\mathbf{n_r}$ denote the number of components in **S**. For **C** = {$\mathbf{C_3}$}, **S** = {$\mathbf{C_2}$, $\mathbf{C_3}$} with $\mathbf{n_r}$ = 2. For **C** = {$\mathbf{C_5}$}, two **S**'s with $\mathbf{n_r}$ = 3 exist: {$\mathbf{C_7}$, $\mathbf{C_6}$, $\mathbf{C_5}$} and {$\mathbf{C_1}$, $\mathbf{C_4}$, $\mathbf{C_5}$}.

Aggregating these two disjoint sequences (one with **C** = {$\mathbf{C_3}$} and another with **C** = {$\mathbf{C_5}$}) for **C** = {$\mathbf{C_3}$, $\mathbf{C_5}$} results in **S** = {$\mathbf{C_2}$, $\mathbf{C_3}$, $\mathbf{C_7}$, $\mathbf{C_6}$, $\mathbf{C_5}$} and {$\mathbf{C_2}$, $\mathbf{C_3}$, $\mathbf{C_1}$, $\mathbf{C_4}$, $\mathbf{C_5}$} with $\mathbf{n_r}$ = 5. However, for **C** = {$\mathbf{C_3}$, $\mathbf{C_5}$} a better solution exists: **S** = {$\mathbf{C_1}$, $\mathbf{C_4}$, $\mathbf{C_3}$, $\mathbf{C_5}$} with $\mathbf{n_r}$ = 4. Therefore, a better solution may be obtained if two or more components are disassembled along a common sequence. This motivates the need for multiple **SD** analysis.

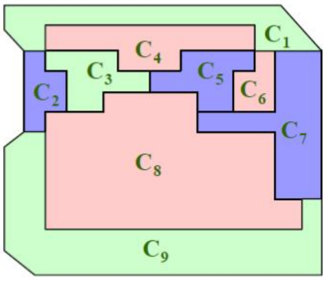


Fig. 8 - Test assembly to illustrate multiple selective disassembly problem

The geometric constraints in this research are of two types:

- *Spatial Constraints:* Constraints imposed in assembling or disassembling of a component due to the spatial position and geometry of all other components in **A**.
- *User-Defined Constraints:* Constraints imposed by the user on the component geometry that restricts some assembly/disassembly operations.

User-defined constraints include component grouping (two or more components are grouped as a sub-assembly) and directional constraints (one or more possible assembly or disassembly directions for the components are constrained).

RESEARCH TECHNIQUE

In real conditions of equipment maintenance can vary not only joints parts type going into it, but also a degree of their effect on an environment (chemical, radiological danger, etc.), that by all means leads to change of a set of the methods involved a disassembly (Figure 9) [6,7,9,11,12,15].

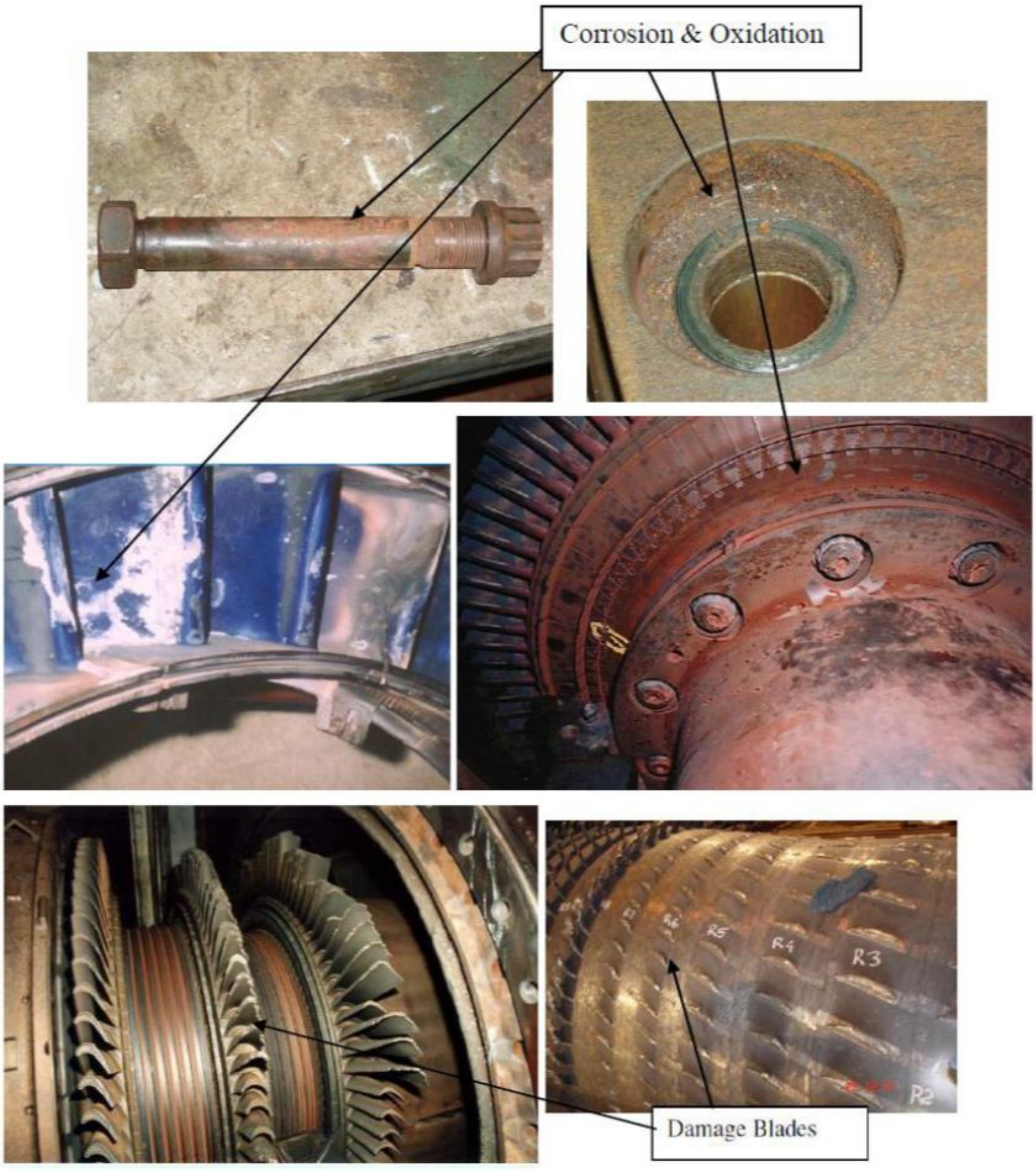


Fig.9 - Gas turbine compressor damage cause and results

The object may come from out side and hit the component causing damage to the components and this type of damage is popularly known as **Foreign Object damage** (FOD). Or the object may be generated within the turbine and may hit the component causing damage to the components and this type of damage is known **as Domestic Object damage** (DOD). This is most common type of failure in gas turbine and takes place due to premature failure of gas turbine components. As mentioned above that the failure is due to impact and for impact failure, the material is to be hit by an object and this object may be external or internal, hence further investigation done on each and every stages of moving and stationary blades of compressor to identify the source of object.

Damage due to Foreign Object

If the damage was due to foreign object, then the material has to travel from out side the Gas Turbine, and it has to be entered in to the Gas turbine Compressor through Compressor inlet air plenum air flow path only.

Damage due to Domestic Object

As the probability of damage due to FOD has already been ruled out therefore, the damage has to be due to DOD, in order to find the source of Domestic Object, when the compressor mid casing was opened, it was found that all most all moving & stationary blades have failed from the root just above platform with massive deformations and failed surface are totally distorted (clockwise). Therefore, though a nos. of moving & stationary blades have failed still question arises which has/have failed first and whether they have failed of their own (due to any reason) or they have also been hit by an object and this object has be generated with in compressor.

Now Domestic Object will generate only because of any one or combination of the following:

1. Something left during last inspection
2. Failure of fixing material and hitting the other components
3. Dislodging of metallic piece from stationary blade and hitting the other components.
4. Dislodging of metallic piece from moving blades and hitting the other components.
5. Dislodging of metallic piece from moving and stationary blades and hitting the other components.

THE RESULTS OF RESEARCH

Offered the new approach, which considers consequences of maintenance of the complex equipment, such as a gas turbine compressor. The product, from the point of disassembly technique, view is represented as set of parts joints that going into it.

Thus the period of product maintenance is represented as the function $E = f(t,u,v)$ that depending from of some factors:

t – time of maintenance;

u – conditions of maintenance;

v – degrees of residual effect on an environment.

The factor of time – for long time of parts maintenance even in normal conditions occurs change of an aspect of the connection, linked for example, to wear of pairs abrasion, change of parts physical properties being in contact (drying of rubber seals, contact surface magnetization and etc.).

The maintenance conditions factor – effect of an excited environment, a dust content of a working area, effect of a heat, heavy loadings, maintenance in hard radiation conditions (heightened radiation), etc.

The factor of a degree of residual effect on an environment – defines a degree of consequences of unfavorable maintenance conditions effect any product as a whole, and details going into it in particular (explosion hazard, residual radiation, biological danger, etc.).

All the above-stated factors influence, separately and in the set, not only on transformation of joints aspects, but also on generation of sequence of selective product disassembly up to the costing parts. Besides the choice of industrial conditions on repair shop and means of technological equipment also depends on a combination of their influence.

The set of decisions of the given problem at a qualitative level is described by the equation (a necessary condition):

$$\forall_{\psi \in \Psi} R_{\psi} = \{R \mid \gamma_R^{\min} \le \gamma_R \le \gamma_R^{\max}\},$$

i.e. for all existing candidate solutions of a problem (set of techniques) the included criteria on quality of process is in the field of acceptable values $\lambda_{P_0}^{\min} \le \lambda_{P_0} \le \lambda_{P_0}^{\max}$.

The decision of a problem at a technological level (sufficient condition):

$$\exists_{\xi \in \theta} R_{\xi} = \bigcap_{\psi=1}^{\chi} R_{\psi} \vee \exists_{\phi=1}^{\varphi} M_{\phi} \vee \exists_{\zeta=1}^{\chi} STO_{\zeta} \vee \exists_{\varepsilon=1}^{\tau} TP_{\varepsilon},$$

where

$\exists_{\xi \in \theta} R_{\xi}$ – the existing candidate solution of a problem; $\bigcap_{\psi=1}^{\chi} R_{\psi}$ – set of candidate solutions of the problem, satisfying to a necessary condition;

$\exists_{\phi-1}^{\varphi} M_{\phi}$ – presence of methods of the decision of a problem for each variant;

$\exists_{\zeta=1}^{\chi} STO_{\zeta}$ – presence of means of the technological equipment, capable to realize necessary methods; $\exists_{\varepsilon=1}^{\tau} TP_{\varepsilon}$ – presence of necessary technological conditions for means of technological equipment under each method.

In this case the set is shaped of technological cost prices of candidate solutions of a problem satisfying necessary and to a sufficient condition, according to expression:

$$\{C_{P_0}\} = \bigcup_{k\in X}\{C_{P_0}(k)\left| \begin{array}{l} \exists_{\xi\in\theta} R_\xi = \bigcap_{\psi=1}^{\chi} R_\psi \vee \exists_{\phi=1}^{\varphi} M_\phi \vee \exists_{\zeta=1}^{\chi} STO_\zeta \vee \exists_{\varepsilon=1}^{\tau} TP_\varepsilon, \\ \forall_{\psi\in\Psi} R_\psi = \{R \mid \gamma_R^{\min} \le \gamma_R \le \gamma_R^{\max}\} \end{array}\right.$$

The optimization problem by economic criteria (a minimum of the technological cost price) then is represented expression:

$$P_0^{opt} = \underset{C_{mex}\to\min}{\ell im} P_0 \Big| C_{mex} \in \left\{C_{P_0}\right\}.$$

CONCLUSION

The basic idea of the concept resulted in operation consists in development of methodology of a system approach to projection of the highly effective technological systems applied at repair and modernizing of heavy duty gas turbine compressor. Practical application of the offered approach will allow to increase quality and safety of special assignment, and introduction of the formalized technique in conditions of real manufacture will allow increase in level of efficiency and the use of available means of complex technological equipment.

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Received 17.03.2015

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