NDT Automated Systems for Technical Objects' Residual Life Evaluation

Vladimir V. KLYUEV, Andrey S. FURSOV,
Association SPEKTR- GROUP, Moscow, Russia

Abstract. To provide the object' residual life estimation it is necessary to arrange its health monitoring by means of various NDT methods. Various NDT methods give different type output data. It can be visual, quantitative, logical and some other data types. All these data should be interpreted and correlated to make a decision on the object residual life.
Currently used are simplified methods of residual life evaluation, i.e. based on one parameter measurement; this can be wall thickness, coercive force of ferromagnetic material, residual magnetic field strength and some others.
In the paper proposed approach to development of object residual life automatic estimation system (ORLEAS) based on measurement and forming of basic diagnostic parameters area; development of relevant reference quantities data base; diagnostic parameters area partitioning (clustering) into non-overlapping areas that characterize the actual object health and, finally, work out of decision rule that make it possible to classify the object health as specific for certain area at certain time.

Introduction

Problems of estimation and prolongation of a resource of safe operation of machines and constructions have got an exclusive urgency in all industrially developed countries during the last decade. For Russia the special importance of their solution is explained by reduction of volumes of equipment production used for replacement of the machines and constructions put out of operation. First of all it concerns the objects of thermal and nuclear power, oil- and gas pipelines, chemical industry, ground, water and air transport, industrial and civil engineering. On the territory of Russia, where half the population of Russia lives, there are about 100 thousand hazardous production facilities. Each day in Russia not less than 2 technogenic accidents occur. In perspective the situation is predicted as one even more dangerous. The most important defects in industry and construction activity - corrosion, wear and fatigue result in accidents, the losses from which make annually more than 100bln. dollars. If in addition to above to add the poor training of personnel, the problem of technogenic safety is even more aggravated.

1.1. General approaches

For search of defects and forecasting of condition of objects it is necessary to measure the large number of diagnostic physical parameters, which they divide in the following groups: kinematic, geometrical, static, dynamic, thermal, acoustic, electrical and magnetic, mechanical, atomic physical, and also based on molecular properties of substances and radiations. The measurement of physical parameters is laid in the basis of various methods and means of technical diagnostics with the help of which one analyzes condition of an

object. It includes: electrometry, vibroacoustics, flaw detection, structure analysis, introscopy, measurement of mechanical properties, structure of a substance, sizes, velocities, accelerations, forces, deformations, pressure, temperature, time, mass, humidity, consumption, level and others.
Methods and means of technogenic diagnostics use more than 100 physical techniques of testing and more than 1000 types of devices for flaw detection, structure analysis, testing of physical and mechanical properties and defects sizing, vibrometry, etc.
Today the main direction of development of non-destructive testing and technical diagnostics is creation of object residual life automatic evaluation system (ORLAES, abbreviation in Russian – ASOORO). For this purpose the automated diagnostic support with high reliability and the best metrological and technical characteristics, with high efficiency and measurement of many diagnostic parameters is required. As an example in Fig. 1 some diagnostic instruments for gas pipelines, aeronautical and rocket engineering are shown.

Fig. 1. Samples of instruments for technogenic diagnostics, total expenses should not exceed 30% of diagnosed object cost.

It is very important to note, that the measures on restoration of technical condition of the in service equipment should be carried not upon set dates and norms, but on the basis of diagnosing. For example, the evaluation of main gas pipelines operation mode should be carried out not on the basis of the passport characteristics, but in view of the actual, diagnosed in time characteristics of mechanical properties and wall thickness.
Only the transition to selective methods of repair on the basis of the results of non-destructive testing and technical diagnostics make it possible to solve a task of safety increase with simultaneous reduction of repair work volumes and, hence, reduction of the expenses at least in 3 times.

1.2 Problems to be solved

In the process of the ORLAES development the following problems should be solved:
– Numerical analysis of objects' initial, used-up and residual lifetime,
– Substantiation of design and actual service life and residual lifetime;
– Evaluation of health of bearing elements' constructional materials with taking into consideration the initial technological heredity and arising operational damages;
– Determination of nature and macro- and microflaws sizes as well as load-bearing structures deformations.

It is important, that the residual life should be determined with higher scientific and methodical accuracy, than the design and initial ones.

1.2.1 ORLAES model

The task of the ORLAES model working out can be divided in two parts:
– Development of systems at a stage of object design;
– Development of systems for an object which is in operation.

For both cases the mathematical models of wear is made, the periodicity of testing and the list of technical parameters characterizing the health of an object are determined/ In the process of the model development one takes into account the strength properties of materials; expected operation conditions (loads, factors of corrosion presence and development, etc.).

When the model of the wear of the object in operation is made, one estimates the required periodicity of testing, right up to the continuous automated monitoring. The criteria can be as follows: limiting values of some physical parameters of object units and components; initial information about design service life that takes into account object operation life and conditions; statistical data collected in the process of the same type technical systems operation, and also opinion of the experts on operation and non–destructive testing.

The set of technical parameters of the object currently available (forming space of technical parameters) depends on object's initial state, i.e. at the beginning of operation, on the mode of object functioning, and also on operation conditions trends.

In this case under the operation conditions one understands the working loads, systematic and random factors of corrosion development, wear resistance and others, which generally can be defined as a set of destroying impacts. The object technical parameters change is described by the state equation (1).

The object operating mode is understood as the set of technical processes developing in time, while each of the processes is characterized by set of its own working parameters.

In the ORLEAS system the object technical parameters ensemble is estimated and judged upon direct or indirect measurements results. Obtained measurement results depend on the object technical parameters actual at the moment of measurements and conditions, under which the measurements were conducted. The given stage is described by the measurements equation (2).

Based on obtained measurements ensemble the estimation of the object technical parameters true values is made. This stage is described by its own evaluation equation (3).

Finally the object actual condition (state space vector) is evaluated. In this case the estimation is done upon object technical parameters true values ensemble collected in the given conditions (equation 4).

1.2.2 Residual life calculation

The object residual life calculations are made on the basis of constructed mathematical model. The residual life is defined by: ensemble of object technical parameters estimations; state equation; operation conditions; actual object state and set of limiting technical parameters (equation 5).

The above-enumerated equations look as follows:

$$x(t) = F([(t_0), u_{[t_{0,t}]}) \qquad (1)$$

$$y(t) = G([(t), u(t)) \qquad (2)$$

$$\hat{x}(t) = H(y(t)), \qquad (3)$$

$$\Phi(t) = \Psi(\hat{x}(t), u(t)), \qquad (4)$$

$$R(t) = W(t, \hat{x}(t), u(t)), \qquad (5),$$

where (1) – state equation,

(2) – measurements equation,

(3) – evaluation equation,

(4) – estimation equation of object actual state,

(5) – residual life evaluation equation,

$x(t)$ – vector of technical (diagnostic) parameters,

u(t) – object operation conditions at the current moment of time,

$u_{[t_0 t]}$ – object operation conditions for the time interval *[t_o,t],*

K – vector, characterizing object operation mode,

y(t) – (direct or indirect) measurements conducted in the process of testing – random variable,

$\hat{x}(t)$ – technical condition vector estimation,

Ф*(t)* – object actual state estimation at given moment of time,

R(t) – residual life evaluation at the moment of time *t*,

$\overline{x}$ – technical parameters limiting values.

The given model is made for each object component essentially influencing its service life. The residual life of the object, as a comprehensive whole, is evaluated upon its component in the worst state.

The estimation of technical parameters true values according to equation (3) is a task of recognition of the condition, in which there is the test object, and the probabilistic approach can be applied for the task solution.

1.3 Practical aspects of ORLAES implementation

At the stage of new object design and in case of implementation of the object residual life evaluation automated system the means of monitoring of the actual condition in the most critical points are taken into account. Under critical points understood are calculated places of stresses concentration, possible centers of corrosion occurrence and other defects. At the design stage it is also necessary to provide an access to critical points to carry out planned diagnostic actions.

From the constructive point of view it is necessary also to provide access to expected critical points to carry out periodic examination by "non-monitoring" methods like liquid penetrant and magnetic particle testing, metallography, radiography that, in fact, make the picture of an object actual condition essentially more detailed.

The means of an object continuous monitoring should have technical resources of data transfer providing forming of network, and its connection to a data processing server. For this purpose the most efficient and practical is use of wireless networks, less dependent on external conditions and more reliable than usual wire ones.
For proper strength, service life and crack resistance substantiation required is a complex of calculations of stress-deformed status of load-bearing elements including determination of nominal and maximal stresses, their amplitudes, maximal and minimal operation temperatures, numbers of operation cycles and service time.
To prove the correctness of strength, service life and crack resistance characteristics used as criteria usually arranged and conducted are evaluation tests that are performed with the help of standard, unified or special laboratory samples. In those cases, when new structures are designed, they carry out tests of models, bringing them up to the limiting state, i.e. causing inadmissible deformation, ductile or brittle failure, formation and development of cracks.

1.3.1 ORLEAS structure and development stages

As a rule, the ORLEAS comprises the following phases:
1. Consecutive and systematic measurements of certain parameters,
2. Revealing of above parameters changes occurring during operation and comparison of obtained information with the initial one,
3. These parameters change forecasting.

When developing the ORLAES it is necessary to perform the following works:
- To determine required hierarchical levels for each object of diagnostics;
- To determine diagnostic parameters for each unit that is a part of the diagnosed object;
- To determine the required efficient volume of measurements of the object diagnostic parameters;
- To make a decision on the set of instruments to be used in diagnostic systems and provide mathematical support of system operation;
- To solve the task of object serviceability forecasting in real time.

If at the stage of analysis of failures' mechanism performed in the process of object (designed for a long service life) operation not to take into account the failures caused by off-design overloads; natural impacts and design, repair or operation errors, then remaining sources of failures occurrence can be related mainly to two groups:
- Formation and growth of fatigue and corrosion-fatigue cracks up to dangerous ones or inadmissible sizes;
- Corrosion, resulting in reduction of thickness of the load-bearing elements up to dangerous or inadmissible sizes.

So, destruction or damage caused by cracks growth is a typical form of limiting state of pressure vessels, which are high-loaded objects widely used practically in all areas of engineering (nuclear and thermal power, transport, chemical and oil-and gas industry).
As an example the scheme of a high pressure vessel residual life evaluation based on coercive force of its ferromagnetic material is shown in Fig. 2.

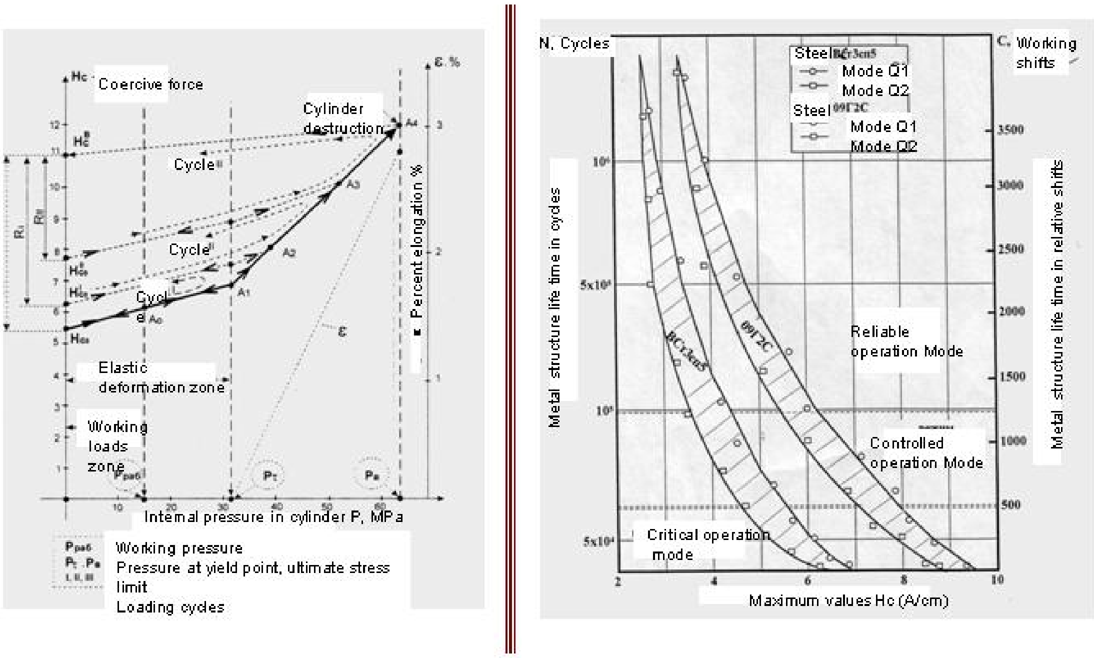

Fig. 2. High pressure vessel residual life evaluation based on magnetic testing.

The scheme of residual life evaluation general procedure is presented in Fig. 3. The diagnostic tree in Fig. 3 demonstrates a number of levels corresponding to basic diagnosed parameters of an object.

The scheme of the ORLEAS presented in Fig. 4 includes stages of: technical documentation analysis; functional diagnostics; examining surveys; analysis of mechanisms of damages development and normalization; criteria selection based on calculations, experiments and study of mechanical characteristics with following decision-making on possibility of object further operation or its repair or change of operation modes.

In Fig. 5 the scheme of ORLEAS for pipelines is presented, where the formula, determining a residual life based on measurement of thickness of a pipeline wall and speed of corrosion propagation is given.

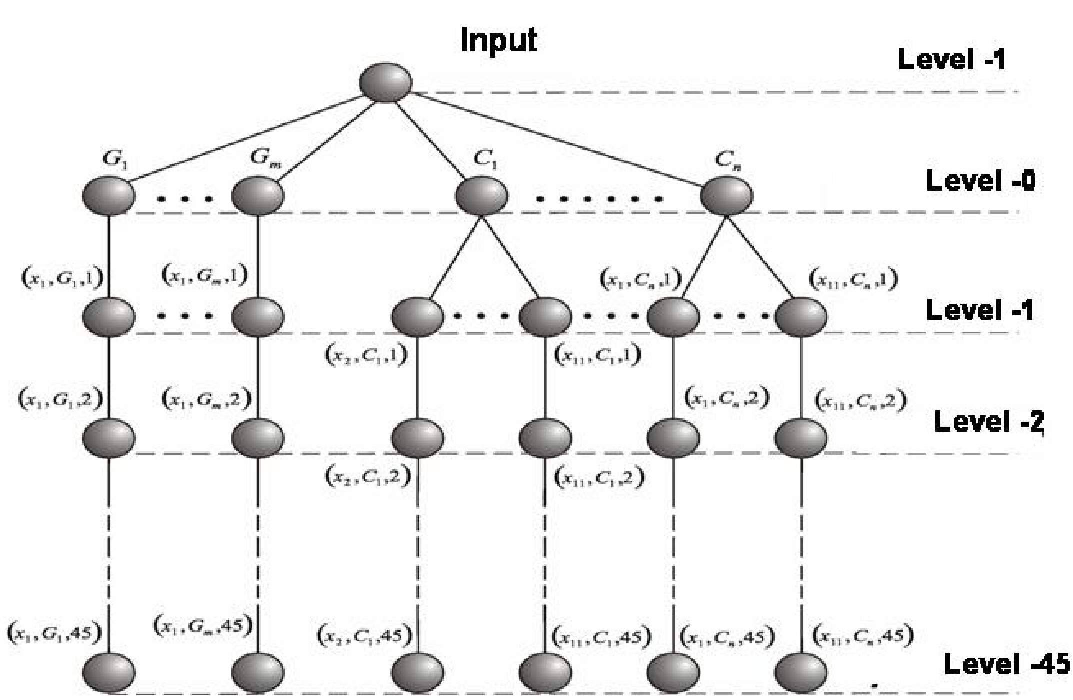

Fig. 3. Diagnostic tree for residual life evaluation.

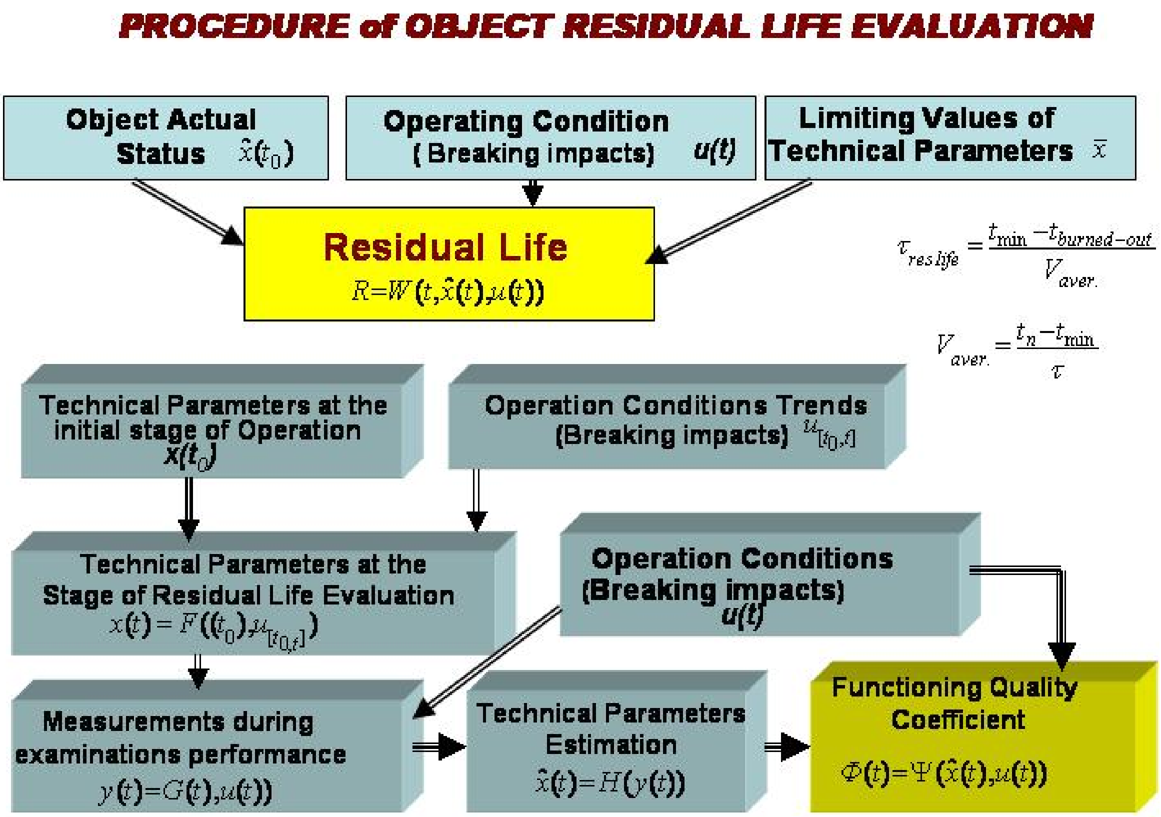

Fig. 4. Procedure of residual life evaluation

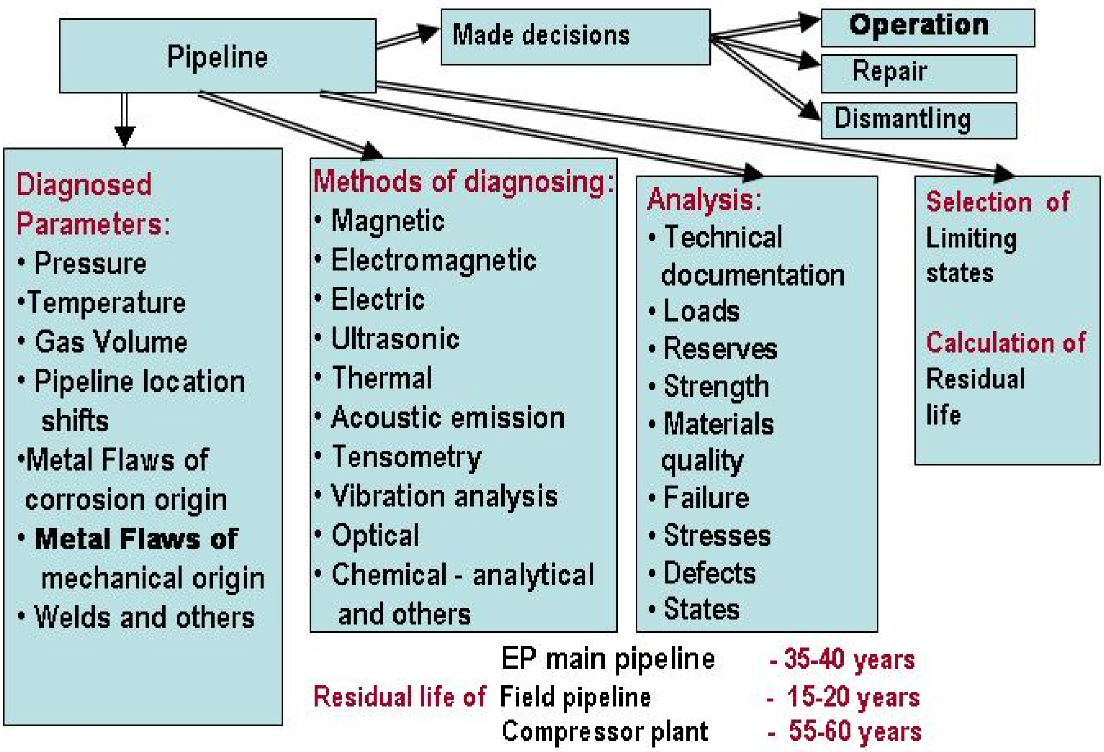

Fig. 5. Scheme of pipeline residual life evaluation.

Conclusion

Currently in practical use for the task of residual life evaluation a very simple approaches are used. In the nearest future it will be vitally important to solve multi parametric task requiring development of poly parametric diagnosing and software to be integrated in the ORLAES systems. Such systems, from one side, should have optimal number of measuring channels and from the other – provide expenses minimization. Expected expenses for development of automated systems for residual life evaluation should not exceed 30% of the project cost.