NEW APPROACH TO THE INDUSTRIAL SAFETY ENSURING

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Abstract

Industrial safety is the state of security of human and society’s vital interests from failure of hazardous industrial objects. Thus, notion about fracture of loaded materials is the physical basis of the industrial safety. There are two main approaches to this notion.

Mechanical approach is traditional. It considers fracture as force act which comes after the tensile stress is exceeded. Implementation of this approach leads to non-destructive testing (NDT). At this problems with definition of dangerous defect and service life prolongation arise. Manufacture stops are needed and hydraulic (pneumatic) tests are carried out.

It was shown in 1950s that notion about force fracture is wrong. New approach has appeared – kinetic theory which considers fracture at stresses lower than the tensile stress as time process of the thermally activated disintegration of meta-stable state. Meta-stable state of the solid body is caused by the loading. In this aspect industrial safety is in the determination of the remaining life as function of the force-temperature influence, defects, corrosion, etc.

Fracture process in kinetic theory contains two stages: delocalized accumulation of stable micro-damages and macro-crack growth. The shift of stages (macro-crack formation) is chosen as the limit state for the determination of the remaining life. In spite of the survivability of the constructional materials exploitation of the industrial objects with growing macro-cracks should be stopped in purpose of the industrial safety ensuring.

Criteria of macro-crack formation have been established – concentration criterion which allows to perform long-term prognosis and P-criterion which allows to determine the moment of growing macro-crack formation.

We use acoustic emission (AE) method for the registration of damages, but other methods are also allowable.

These criterions have been verified in laboratory conditions on specimens with welding joints during cyclic bend and tubular specimens during statically loading with inner pressure at high temperatures.

We have developed method for the service life prolongation of hazardous industrial objects on the basis of the given above principles. We have been applying it for boiler, gas and chemical equipment in Russia for more than 15 years.

Keywords: industrial safety, fracture, accident, acoustic emission, macro-crack, remaining life.
1. Introduction

Industrial safety is the state of security of human and society's vital interests from accidents. Accident is the fracture of constructions and (or) technical devices (vessels, pipelines, boilers, cranes, etc.) [1]. Hence it follows, that the notion about fracture (loss of strength) of materials is the key for the industrial safety ensuring.

Humanity had to resolve the problem of strength during whole history of its existence. No one construction should break down during its exploitation. However, in spite of all efforts the science about strength is behind other disciplines, which seem at first sight to be more difficult and effective. The internal structure of atoms and stars seems to be more clear nowadays than the processes, taking place in the loaded solid body and leading to its fracture.

Frequent accidents on pipelines, for example, starting from gas mains and up to endless fractures of municipal heating mains, show the unsatisfactory state of the used notions for the industrial safety ensuring. Accidents lead to people death and cause huge social, ecological and economical damage.

There two main existing notions about the fracture: force (mechanical approach) and thermo-kinetic (kinetic conception of strength). We will compare these two notions.

2. Mechanical approach

Since Leonardo da Vinci (~1500) and Galileo (~1638) and till nowadays fracture is considered as an instantaneous event caused by the critical force (called the tensile strength $V^*$), which overcame the material resistance (cohesion of atomic bonds). Such notion seems to be evident for us from the childhood: we interpret fracture (of the cap, glass, etc) as a result of impact, excess of the tensile strength.

It was proved in 1950’s by academician S.N.Zhurkov in Leningrad Physical-Technical Institution that the notion about force fracture is wrong and the thermo-kinetic nature of fracture was established.

3. Thermo-kinetic nature of fracture

The energy of thermal atomic oscillations (phonons) and its fluctuations plays the defining role in the solid bodies fracture. Critical thermal fluctuations absorb excess phonons (born by the loading) and evolve into the stable breaks of the material continuity – germ of cracks - defects.

The waiting time of critical fluctuations and damages accumulation destroys, but not the force.

The fracture can take place at every stress $\sigma$ depending on the loading time $\tau$ and temperature $T$:

$$\sigma = \frac{U_0 - kT \ln \frac{\tau}{\tau_0}}{\gamma}$$
The initial strength value can decrease considerably after the long time of exploitation, especially for composites and rocks.

Existing system of the industrial safety is based on the force approach and needs to be reviewed from the modern positions of the thermo-kinetic approach.

4. **Existing system of the industrial safety ensuring.**

It is based on the force notion about fracture and stands on “three pillars”:

4.1. **Safety margin, allowable stress.**

The stresses $\sigma < \frac{\sigma_u}{n}$ are allowed. The value $n > 1$ is called safety margin and $[\sigma]$ – allowable stress. Stresses, which are lower than the allowable, are considered to be safe, not able to cause the fracture. The values of the safety margin are regulated by the normative documents. So, for steel vessels $n = 2,4$.

The allowable stress determines the minimal value of the wall thickness for the vessel with inner diameter $D$ and operating pressure $P$:

$$S_p = \frac{DP}{2[\sigma] - P}.$$ 

4.2. **Non-destructive testing (defects detection).**

Huge attention is paid to defects detection in the object material by various physical methods. New branch of scientific-technical investigations has arisen - non-destructive testing. It is considered, that defects decrease the safety margin. However, the influence of the detected defects on the possibility for exploitation prolongation is defined only by the normative documents without sufficient substantiation.

4.3. **Overloading tests.**

The overloading test (hydraulic, pneumatic, etc) for strength is obligatory for all industrial objects. The object is “overloaded” by pressure $P_{\text{test}} = 1,25[\sigma]$.

The logic of the overloading test consists in the following: if the object stood the pressure $P_{\text{test}} > [\sigma]$, than the operating pressure $P \leq [\sigma] < \sigma_u$ is safe.

5. **Estimation of the existing system of the industrial safety ensuring.**

1. The more the safety margin the higher the safety. The more the safety margin the more the wall thickness and the higher energy and material inputs, that is not economically. How to choose an optimum?
2. Where is the border between the allowable and dangerous defects? When the exploitation can be prolonged and when the repair or the replacement of the object should be done?
3. Carrying out of the overloading test (in chemical, gas industry, etc) often causes considerable losses by the manufacture stop, emptying, degassing, etc. Cases of the fracture during overloading test or soon after it are known. As a result the overloading test is not carried out usually. Is it possible to exclude the overloading test from the object testing?

4. How often the industrial safety expertise should be carried out? What is the object remaining life? Own life-time of the loaded material is not taken into consideration. Time limitations are put through the external influences: corrosion-erosion wear, cyclic loadings, which role is overstated.

There are no argumentative answers on these fundamental questions in the force approach to the fracture notion that shows the inadequacy of the existing system of the industrial safety ensuring. Its elements are uneconomical, energy-intensive, unfeasible and unreliable.

The modernization of the industrial safety ensuring system should consist in the refusal from the force approach and consideration of the thermo-kinetic nature of the fracture.

6. Modernization elements of the industrial safety ensuring system

1. Dependence of the remaining life from the safety margin

Force approach supposes indestructibility at the safety margin \( n > 1 \). Thermo-kinetic nature of the fracture limits the life-time of the loaded material at every safety margin value, leading to the notion of the remaining life \( \tau \). This is own time of life (without corrosion-erosion influences).

The dependence \( \tau(n) \) for carbon steels established by us is given at fig. 1.
As it can be seen, the remaining life for vessels is almost infinite at normative value \( n = 2,4 \) and room temperature, but at the temperature 400 °C the remaining life is just 10 years. Thus, the safety margin choice is dictated by the temperature and the exploitation period.

2. Allowable damages and dangerous cracks

According to the new conception, loading increases free energy of the body \( F = H - TS \), which decreases during the heat usage (thermal activation) by plastic deformation (increase of the entropy \( S \)) and the generation of the continuity breaks (decrease of the energy \( H \) in the form of acoustic, thermal and electromagnetic emissions). The loaded body doesn't resist to the fracture, it aims to break down and to drop the load. The continuity breaks are stable due to the generation mechanism and heterogeneous structure of the bodies. The accumulation of the continuity breaks is divided on two stages.

![Fig. 2. Two-stage model of stable continuity breaks accumulation.](image)

Damages appear chaotically on the first stage. As a result of it spontaneous clustering leading to the growing clusters of damages formation (second stage) takes place. Generation of damages on the first stage is allowable. The transition to the second stage is dangerous.

Registration of acoustic emission at damaging is informative during the exploitation without overloading tests.

K- and P- criterions for the stages shift are established.

7. References