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NON-DESTRUCTIVE TESTING OF DRILLING OIL AND GAS EQUIPMENT AND TOOLS

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Abstract*: One of the most effective ways of preventing drill equipment (pipe strings) failures is the evaluation of real technical state of threaded joints at various exploitation stages using methods of non-destructive testing. Detection of cracks in pipe body is reviewed. The parameters of inspection are determined for various standard sizes of pipes.Flaw detection in pipe threaded joints with triangular and tool-joints threads is discussed. The ultrasonic method is proposed to use. The special techniques of non-destructive testing are described. The most interesting is technique that allows flaw detection in heavy-weight drill pipes threaded joint without disassembling. Also a novel technique for quality inspection of thread stripping (bonding strength and leakproofness) is proposed. Threoretical basis of this technique is discussed. All techniques are impemented in real technical means that are showed and mentioned.*
Key words*: non-destructive testing, ultrasonic, drilling equipment, pipes*

1. INTRODUCTION

The state-of-art of reservoir and oil-field development is accompanied by increasing set of technical (high pressures and temperatures, corrosive mediums, deep wells etc.) and ecological problems. All these factors cause the problem of safe failure-free operation of oil and gas equipment.

Drilling equipment (especially pipe strings) failure analysis showed that the major part of all failures (up to 50%) is caused by seal failures and loss of strength of threaded joints (corrosion-fatigue destruction, deterioration, shear etc.). One of the most effective ways of preventing such failures is the evaluation of real technical state of threaded joints at various exploitation stages using methods of non-destructive testing.

A considerable experience in development of techniques and technical means for defectoscopy of pipe threaded joints was accumulated in Ivano-Frankivsk National Technical University of Oil and Gas and RPC ZOND over last 30 years.

2. DETECTION OF FLAWS IN PIPE BODY

Inspection techniques that allow detection of flaws of different orientation in pipe body will be reviewed below.

It is well known that the best condition for reliable flaw detection using ultrasonic method is when ultrasonic waves fall at right angle on the defect plane. In fig. 1 the path of ultrasonic wave (UW) in pipe wall is shown. The UW that is emmitted by piezoelectrical transducer P with prism angle β in point A with indicent angle α goes through the pipe wall with one reflection in point D normally to defect plane (point B), than goes back on the same way to the transducer P.

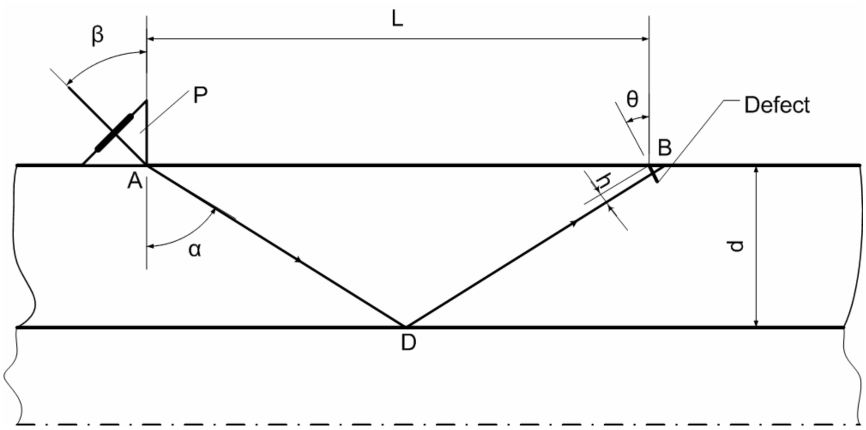


Fig. 1. Propagation of ultrasonic wave in pipe wall with defect

where: θ – inclination of defect plane, degrees; d – pipe wall thickness, m;
h – defect depth, m.

Now parameters of ultrasonic testing can be determined as following:

- UW incident angle:

$$\alpha = 90° - \theta \tag{1}$$

- Piezoelectrical transducer prism angle:

$$\beta = \arcsin\left[\frac{C_{l1}}{C_{l2}}\sin(90-\theta)\right] \tag{2}$$

- Distance between UW incident point and defect:

$$L = \frac{2d\cos\theta - h}{\sin\theta}. \tag{3}$$

Where: C_{l1} and C_{l2} – accordingly longitudinal and transversal ultrasonic waves propagation velocities.

But there can be such conditions when UW falls on defect plane at not quite right angle. The example of ultrasonic wave propagation at this case is shown on fig.2.

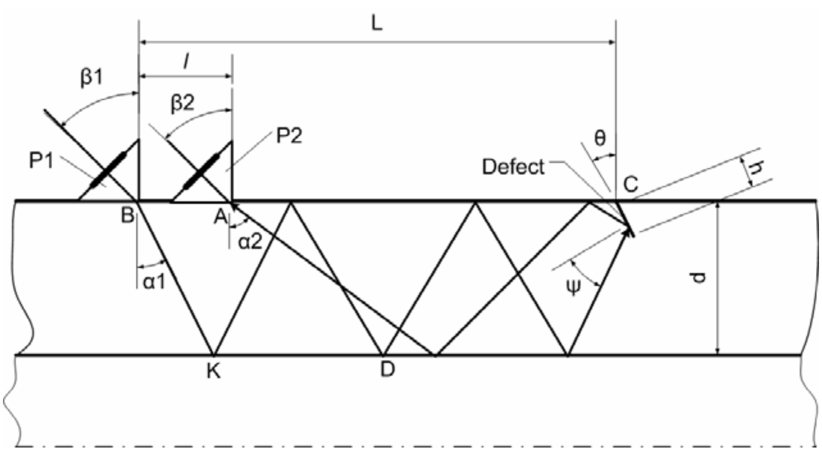


Fig.2. Propagation of ultrasonic wave in pipe wall with defect oriented at the angle ψ to wave path

Parameters of ultrasonic inspection now can be determined using following equations:

- UW incident angle:

$$\alpha_1 = 90 - (\theta - \psi) \quad (4)$$

- UW receiving angle:

$$\alpha_2 = 90 + (\theta - \psi) \quad (5)$$

- emmitting piezoelectrical transducer prism angle:

$$\beta_1 = \arcsin\left[\frac{C_{l1}}{C_{l2}}\cos(\theta + \psi)\right] \quad (6)$$

- receiving piezoelectrcial transducer prism angle:

$$\beta_2 = \arcsin\left[\frac{C_{l1}}{C_{l2}}\cos(\theta - \psi)\right] \quad (7)$$

- distance between receiving transducer and the defect:

$$L = \frac{h\cos\psi}{\sin(\theta - \psi)} - \frac{2d}{ctg(\theta - \psi)} \quad (8)$$

- distance between emmitting and receiving transducers:

$$l = \frac{5d}{ctg(\theta + \psi)} + \frac{2}{ctg(\theta + \psi)} + \frac{1}{tg(\theta + \psi)} - h\frac{\cos\psi}{\cos(\theta - \psi)} \quad (9)$$

where: ψ – UW incident angle on defect plane, degrees.

According to [1] pipes with defects in body with depth more than 3 mm need to be screened. Authors experimentally established [2] that inclination of fatigue defect plane is near 22°. Now if we define h = 3 mm, θ = 22° using equations (4)-(8) we can determine the parameters of ultrasonic inspection of drill pipe bodies for detection flaws of transversal orientation – Table 1.

Table 1. Parameters of ultrasonic inspection of drill pipe bodies

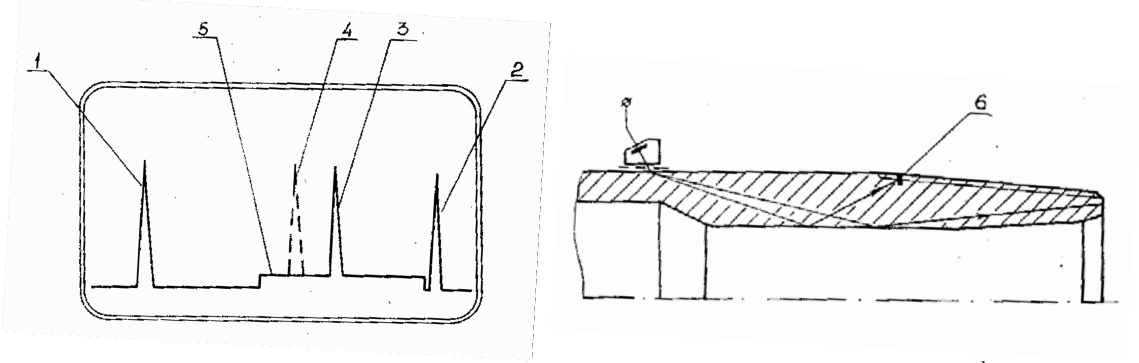
Pipe standard diameter, mm	Wall thickness, mm	UW incident angle α, degree	Transducer prism angle β, degree	Distacnce between UW incident angle and defect L, mm
60	7	79	55.5	72.6
	9			93.2
89	7	79	55.5	72.6
	9			93.2
	11			113.8
114	9	79	55.5	93.2
	10			103.5
127	9	79	55.5	93.2
	11			113.8
140	9	79	55.5	93.2
	11			113.8

3. FLAW DETECTION IN PIPE THREADED JOINTS WITH TRIANGULAR THREAD

Pipes with triangular thread are widely used in oil and gas industry [GOST 631-75, API Spec 5B].

For detection of corrosion-fatigue cracks in threaded joints at early stage of cracking an ultrasonic method was proposed. This method enables flaw detection in threaded pipe joints when pipes are being made-up (with inner barrel lock or with tool joint box).

To establish regularities of ultrasonic wave propagation in threaded joints of different design theoretical and experimental investigations were carried out. It was shown that ultrasonic waves propagation in tapered thread needs to be viewed considering its reflection ability from thread profile which form a set of artificial reflectors with sizes (2.54 mm) that are bigger than fatigue cracks (1-1.5 mm) at the early stage of cracking. Fatigue crack front orientation was experimentally determined for cracks that propagate in thread vee. Effective defectoscopy techniques (Fig. 3) were developed, optimal inspection parameters were established as well as technical means (piezoelectric transducers and scanners) were designed (Fig.4). Using these techniques together with specialized technical means allow to detect flaws in threaded joints during round-trip directly at the drilling rigs.



1 – outgoing pulse; 2 – pulse from butt-end; 3 – pulse from flaw in 5th thread vee; 4 – pulse from flaw in 1st thread vee; 5 - gate; 6 – artificial flaw

Fig. 3. Scheme of flaw detection in triangular pipe threaded joints and flaw detector screen view

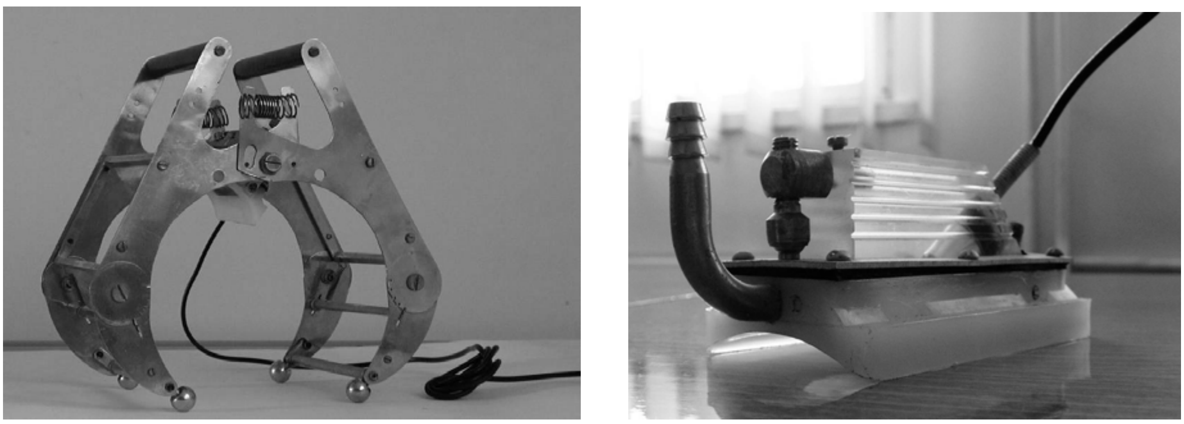


Fig. 4. Special scanner and piezoelectric transducer for defectoscopy of threaded joints

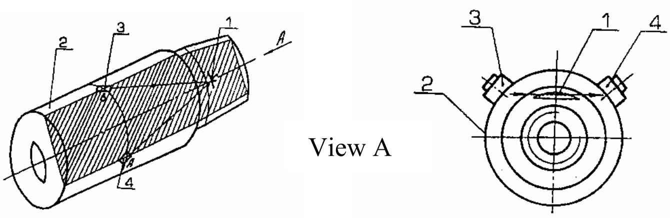
4. DEFECTOSCOPY OF PIPE THREADED JOINTS WITH TOOL-JOINT THREAD

A considerable part of oil and gas pipe grades are connected using tool-joint thread [GOST 5286, API Spec 5B]. These are heavy-weight drill pipes (HWDP) and pipes with enhanced strength and impermeability.

Nowadays approaches for defectoscopy of threaded HWDP joints are not effective because of bigger wall thickness (up to 50 mm) and consequently bigger depth of defect occurrence. A common defectoscopy technique that is used for threaded joints of HWDP foresees inspection from end surface of threaded joint. This technique requires pipes to be dissambled and this result in poor efficiency and danger for personnel during round-trip.

We proposed the method of flaw-detection of HWDP threaded joint in assembled state. The method can be realized using two split-type piezoelectric transducers oriented in a special manner and installed on the outer surface of tool-joint pin. At the same time acoustic axes of transducers should lay in one plane which should be parallel with longitudinal pipe axis and they should intersect at the plane of flaw (Fig. 5). This condition can be reached only with correct ultrasonic wave incident angles and distance between incident points. These two parameters depend on thread joint standard size.

For good flaw detection throughout threaded joint generatrix the system for synchronous scanning along helical line with step equal to thread pitch was developed.



1 - flaw; 2 – inspected pipe; 3,4 – emitting and receiving transducer accordingly

Fig.5. Inspection of tool-joint threads using two transducers

The results of the researches described above were implemented in mobile flaw-detection systems (PLNK-2 and PLNK-5). These systems enable inspection of threaded joints of drilling pipes at drilling rigs, pipe yards and repair depots.

5. QUALITY INSPECTION OF THREAD STRIPPING (BONDING STRENGTH AND LEAKPROOFNESS)

Over the past 20 years heavy industry has been producing drill pipes with threaded joints of enhanced strength and leakproofness (types Buttress, Valurek, VAM etc.). But usage of these pipes for first several years resulted in raising number of failures. The new problem to solve was to determine the failure reasons and develop the corresponding methods for quality inspection. In fact the major part of all breakdowns was caused by seal failure and strength loss in threaded joints. The main reasons of threaded joints failures are the following:

- abuse of pipe strings
- breakdowns during making-up of joints
- imperfect design of pipes
- absence of technical means for quality inspection of threaded joints during operational process.

We pioneered and implemented new approach for quality rating of threaded joints of drilling equipment at different stages of their operational period. This approach consists not only in flaw detection in metal (including corrosion-fatigue cracks) but also in measuring the parameters which determine strength and leakproofness of threaded joint. Traditional methods for threaded joints quality control are based on measurement of indirect parameters (relative tension, torque strength, number of screwable elements turns etc.) and they don't allow evaluating the actual technical state of joint after making-up and after some period of operating. After the investigations it was determined that the following characteristics should be considered as new informational ones:

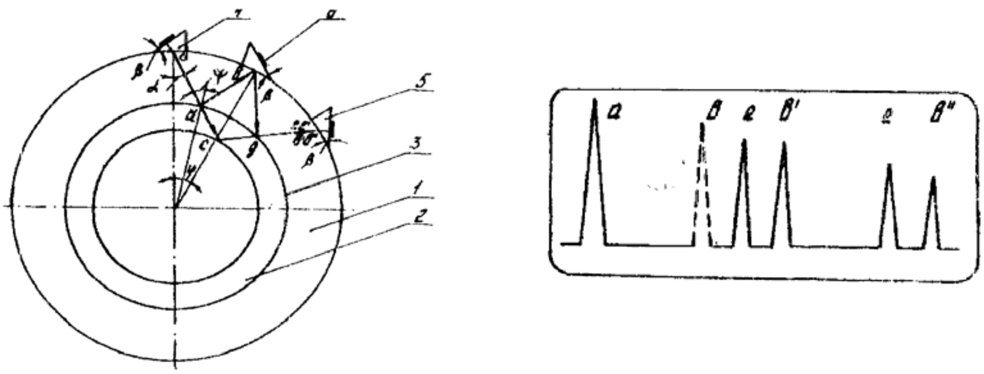
- during making-up process : point of time when the tension in the most loaded elements of a threaded joint is near yield stress of the material;
- after making-up and during operational process: magnitude of actual contact area and level of radial deformations in connected elements.

The efficiency of the use of ultrasonic method of non-destructive testing for measuring parameters that determine threaded joint quality was proved. Theoretical and experimental studies of correlation between operating characteristics of threaded joint and acoustic parameters were done.

The most effective is technique which enables multiple reflection of ultrasonic wave from surface of contact. The use of this technique allows the determination of average and minimal values of tension without scanning the outer surface of joint what result in higher production rate and reliability of inspection. Figures 6 and 7 show the technique implementation. The main point of the technique is that ultrasonic wave hade on the inner surface of the external member should be determined from equation (10):

$$\alpha = arctg\frac{R\sin\frac{\pi}{6n}}{R - r - R[1-\sqrt{4\sin\frac{\pi}{12n} - \sin^2\frac{\pi}{6n}}]} \qquad (10)$$

where: R, r – accordingly radiuses of outer surfaces of external and internal members, m; n – quantity of reflections from inner surface of external member in sector with chord equal to R.



a) b)

Fig.6. Technique for diametrical tension inspection using ultrasonic method (a) and image on defectoscope screen during inspection (b)

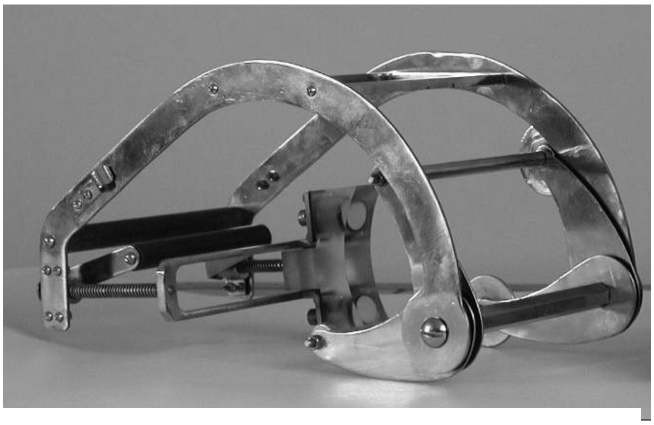


Fig.7. Special scanner for quality inspection of made-up threaded joints

6.CONCLUSIONS

Developed techniques and methods were applied in oil and gas industry of Ukraine by Research and Production Company ZOND for last 12 years. The main technical means that implement the described methods are specialized transducers, scanners of different design, portable and mobile non-destructive systems PLNK-2 and PLNK-5. More details about the innovative technologies developed in RPC ZOND available on http://www.zond-ndt.com

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