Scientific article
UDC 66.023
DOI: 10.52957/2782-1900-2024-5-2-133-139

TORQUE MEASUREMENT DURING STIRRING PROCESS RESEARCH ON THE PILOT PLANT

V. K. Leontiev, O. N. Korableva

Valery K. Leontiev, Candidate of Technical Sciences, Associate Professor; **Olga N. Korableva**, Candidate of Technical Sciences, Associate Professor
Yaroslavl State Technical University, Yaroslavl, Russia
leontievvk@ystu.ru; korablevaon@yandex.ru

Keywords:
torque, torque meters, mechanical stirring, power, piezometer

Abstract. *This article deals with the torque measurement mechanism of the mechanical stirring process. The resulting shear stresses or strains measure the torque. The authors provide a torque meter classification and various methods of torque measurement to accurately measure and control torque. They are important parameters in the design and manufacture of various devices and mechanisms. The paper presents a schematic diagram of a pilot plant to investigate mechanical stirring using the developed torque measurement device without the use of a stroboscope. The method proposed by the authors solves the problem related to simplification of technical torque measurement. The authors calculated the range of liquid level change in the piezometer during the study of the stirring process at the pilot plant, taking into account the minimum and maximum values of pressure in the vessel.*

For citation:
Leontiev, V.K. & Korableva, O.N. (2024) Torque measurement during stirring process research on the pilot plant, *From Chemistry Towards Technology Step-By-Step*, 5(1), pp. 133-139 [online]. Available at: https://chemintech.ru/ru/nauka/issue/5176/view

Introduction

Torque (TM) is a vector quantity characterising the action of a force on a physical body and causes its rotational motion [1]. It is the most important parameter in terms of the rotational force of a shaft. Therefore, the torque measurement is a necessary part of measuring the power transmitted by rotating shafts. It can be calculated as the quotient of the hydrodynamic rotational resistance force by the shoulder of this force [2].

Main body

In general, there are two types of torque measurements: direct and indirect one.

Direct methods are torque measurements using torque sensors. These methods are more accurate than indirect ones.

Indirect methods include measuring the physical quantities that are used to calculate the torque. This could be, for example, measuring the force acting on a lever of known length, or measuring the current and rotational speed of an electric motor, etc. This type of indirect torque measurement can often be faster, easier, and reasonably accurate ***in industrial environments*** compared to direct methods [3].

The most important part of a torque sensor is usually a cylindrical sensing element, which is twisted under the action of a torque applied to it (Fig. 1) [3].

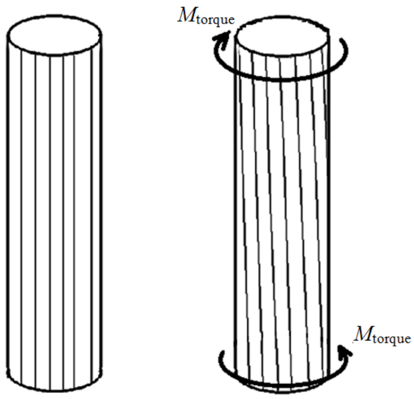

Fig. 1. Cylindrical torque sensor element

The resulting shear stresses or strains are the measure of torque. These stresses or strains are sensed by strain gauges, which are glued to the sensing element at an angle of 45° to its longitudinal axis and integrated into the Wheatstone bridge circuit. Slip rings or signal transmission without slip rings are usually used to transmit the supply voltage and the measuring signal [1].

The torque on the shaft can be determined from the torsion angle of the shaft between two sections along its length. For a solid shaft, the torsion angle φ is determined by the following dependency [2]:

$$\phi = \frac{M_{\text{torque}} \cdot l}{G \cdot \pi \cdot d^4},$$

where M_{torque} - torque, H·m; l - distance between sections, m; G - shear modulus of elasticity of material, Pa; d - shaft diameter, m.

According to this formula, for a given shaft in a section of length l, the torsional angle is proportional to the transmitted torque M_{torque}.

The simplest and most common methods and devices for measuring TM currently used for research purposes are:

1) a method of torque measurement and a device for its implementation [3]. It includes measuring the mutual rotation angle of the base section ends of the elastic shaft, on which optical reflectors are installed; under the action of torque using an optoelectronic transducer consisting of radiation sources and photodetectors;

(2) a torque measuring device containing a shaft and a sleeve fixedly mounted on the shaft. It has a bald area on an outer lateral surface. The sleeve on the bushing is mounted with the option to rotate, in which radial grooves are made, located opposite to the bald spot with angular displacement relative to each other. It also contains a measuring sensor connected to the measuring system and a device for influencing the sensor [4].

The most important components in TM measurement devices are the torque meters. They allow ones to provide accurate measurement and control of torque. It is an important parameter in the design and manufacture of various devices and mechanisms [4, 5]. Therefore, such devices are widely used in various industrial fields, including mechanical engineering, automotive, electronics, etc.

Torque meters can be of various types and designs (Fig. 2).

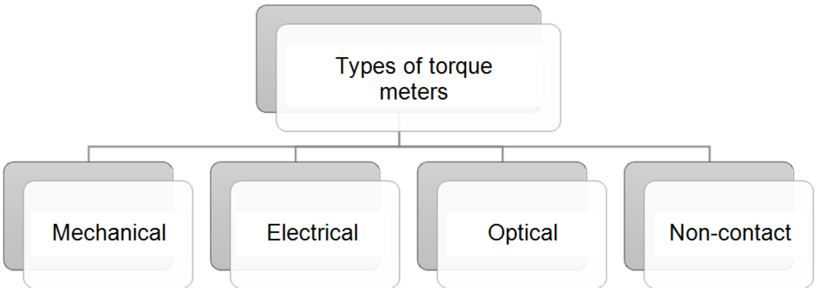

Fig. 2. Classification of torque measuring devices

Each type of torque meter has its own advantages and limitations. The choice of a particular type depends on the requirements and conditions of a particular end use application:

- mechanical TM meters are based on the use of mechanical elements such as levers, springs, and scales. They allow ones to assess TM by measuring the force that occurs during the rotation of an object. An example of a mechanical meter is a torque wrench;
- electrical TM meters use electrical principles to measure TM. They are usually based on the Hall effect or piezoelectricity effect. These meters generate an electrical signal that is proportional to the torque itself. Examples of electrical meters are torque sensors and load cells;
- optical TM meters use optical principles to measure the torque. They are usually based on the use of lasers and optical sensors, provide high measurement accuracy, and can be used in complex and precise applications. An example of an optical meter is a laser torque sensor;
- non-contact TM meters use non-contact methods for measuring the torque. They are usually based on the use of magnetic fields or radio frequency signals. Non-contact meters allow torque to be measured without physical contact with the object being measured. An example of a non-contact meter is an induction torque sensor [2].

The fluid flow in an apparatus with a stirrer can be considered as a flow through a channel having a complex geometrical shape. Due to the finite number of stirrer blades, the fluid flow in the apparatus is transient one [6]. The process of stirring by mechanical stirrers is reduced to an external problem of hydrodynamics - streamline of bodies by the flow of liquid. The problem of external flowing of bodies under stirring conditions can be solved with the help of Navier-Stokes equations and continuity of flow. To solve this problem, the similarity theory is used [7].

According to scientific and others papers and articles, the stirring processes are as follows:

- they are widely used in chemical technology to obtain homogeneous solutions, various emulsions, intensification of heat, and mass exchange processes. Effective stirring in some cases is one of the most important stages of production, and determines the productivity of the technological process as a whole [8];
- they are repeated movements of fluid particles under the action of an impulse transmitted by a liquid or gas jet (hydraulic, pneumatic mixing), stirrer (mechanical mixing).

One of the most common industrial methods is mixing with the use of mechanical stirrers of various designs with rotary, less often translational motion [9];

- they are characterized by intensity, efficiency, and energy consumption. The intensity of the stirring process is determined by the time to achieve a given technological result. Intensity of stirring leads to increase of operating costs for specific energy supplied to the stirred medium and reduction of capital costs due to increase of equipment productivity. The optimal variant is selected according to the technical and economic evaluation of the specific costs minimum value. The efficiency of the process characterizes its quality. It is also determined by the uniformity of distribution or change in the heat transfer coefficient, mass transfer coefficient depending on the purpose of the process [10].

When calculating the mechanical stirring process, the most important quantity to be calculated is the stirring power. It depends on the circumferential velocity, the pressure distribution area, and the pressure drop across the front and back of the stirrer. Considering the operation of the stirrer as a pump, the power N consumed by the stirrer can be theoretically determined by the equation [11-13]

$$N = K_N \rho n^3 d_m^5,$$

where K_N is the power factor; ρ is the density of the stirred medium, kg/m^3; n is the stirrer rotation speed, r/s; d_m is the stirrer diameter, m.

The power developed by the stirrer through the torque [N·m] can be determined by equation [9]:

$$N = 2\pi n M_{\text{torque}}.$$

Researchers from the Department of Chemical Technology of Organic Substances, Yaroslavl State Technical University, Yaroslavl, Russia have modernized a laboratory setup for investigating the efficiency of mechanical stirrers, which uses a TM measurement device [14]. The scheme of the device is shown in Fig. 3.

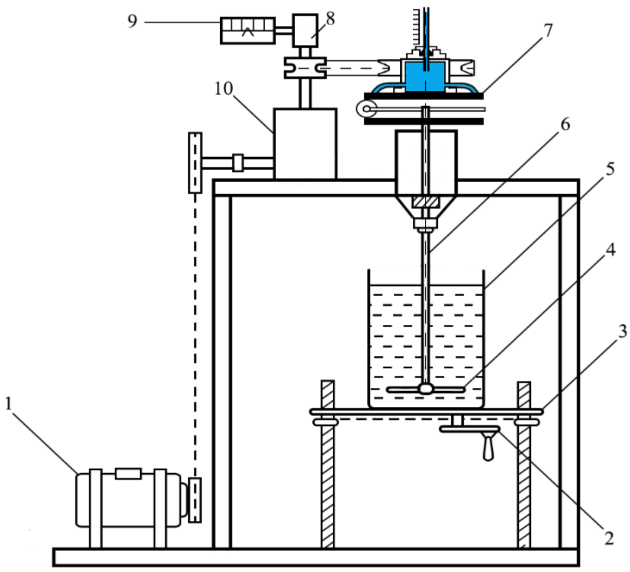

Fig. 3. Scheme of laboratory installation for research of mechanical stirrer's operation efficiency: 1 - DC electric motor; 2 - flywheel; 3 - lifting table; 4 - stirrer; 5 - vessel with stirred liquid; 6 - shaft; 7 - torque measuring device; 8 - tachometer sensor; 9 - speed indicator; 10 - reducer

The stirrer 4 is driven by the DC motor 1 through the gearbox 10. The vessel with the stirring liquid 5 is mounted on the lifting table 3, the movement of which in the vertical direction is achieved by rotation of the flywheel 2. This allows us to change stirrers and set the required depth of their immersion. Torque measurement is performed by device 7. The stirrer shaft speed *n* is measured by an electromagnetic tachometer consisting of a sensor 8 and a speed indicator 9 [15].

The main element of the unit is a device for TM measurement. Previously, a device using a stroboscope was used to measure TM [9]. It has higher manufacturing, operational costa, and health hazards. Therefore, the purpose of the study was to develop a simplified device for measuring TM without using a stroboscope. The design of the device is shown in Fig. 4.

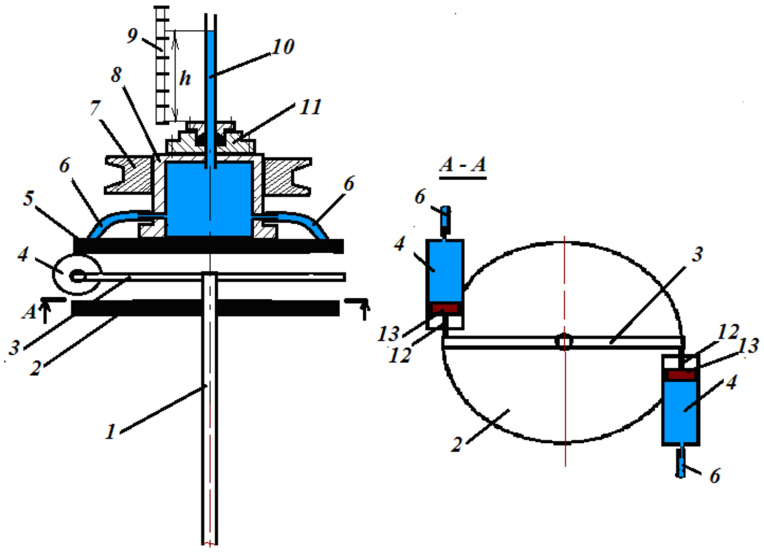

Fig. 4. Torque measuring device: 1 - shaft; 2 - lower half-coupling; 3 - lever; 4 - hydraulic cylinders; 5 - upper half-coupling; 6 - flexible tubes; 7 - pulley; 8 - container for coloured liquid; 9 - fixed scale; 10 - piezometer; 11 - gland seal; 12 - rods; 13 - pistons

When torque is transmitted from pulley 7 to shaft 1, the upper 5 and lower 2 coupling halves are displaced. As a result of lever 3 pressure on the curtains 12 of pistons 13 of hydraulic cylinders 4, an excess pressure in the fluid is formed. The hydraulic cylinders are connected to the container for the coloured liquid 8 by means of flexible tubes 6. This pressure is measured by piezometer 10, which is fixed in the container for the coloured liquid by means of a gland seal 11. The piezometer rotates together with the upper coupling half. The liquid level in the piezometer *h* is fixed visually through the fixed scale 9.

The overpressure in the device vessel is determined by the value of h $p = \rho g h$, where ρ is the density of the coloured liquid, kg/m^3. This pressure is created by the force of the piston pressure on the liquid $F = pS$, where S is the cross-sectional area of the piston, m^2.

The torque through the magnitude of the force F is calculated as $M = Fl$, where l is the length of the lever (shoulder of the acting force), m [16].

The torque value determines the power required for stirring: $N = 2\pi nM$.

The dependence [13] is used to compare the efficiency of different types of stirrers:

$$K_N = f(\mathrm{Re_m}, l_1, l_2, \dots),$$

where $K_N = \frac{N}{\rho n^3 d_m^5}$ is the stirrer power factor;

$Re_m = \frac{\rho n d_m^2}{\mu}$ – modified Reynolds criterion;

d_m – stirrer diameter, m;

μ – dynamic viscosity coefficient, Pa·s.

From the torque value, the shaft diameter of the agitator can be calculated according to the formula [16]:

$$d = 1{,}73 \cdot \sqrt[3]{\frac{M_{\text{torque}}}{\sigma_{\text{per}}}},$$

where σ_{per} is the permissible torsional stress for the selected shaft material; Pa.

The TM variation range, which was from 0.05 to 0.3 N·m, was determined on the basis of numerous experiments on a laboratory unit for investigating the efficiency of mechanical stirrers. Taking the diameter of the hydraulic cylinder 32 mm and the length of the lever 10 cm, the minimum and maximum values of pressure in the device vessel were calculated; they were 625 and 3750 Pa, respectively. The liquid level in the piezometer *h* will then vary between 6.38 and 38.27 cm.

Conclusions

The authors have developed a simplified design of a torque measurement device on a teaching laboratory set-up to investigate the performance of mechanical stirrers.

The range of torque variation was determined as 0.05 to 0.3 N·m.

A hydraulic calculation of the liquid level height in the piezometer was also performed. It varies from 6.38 to 38.27 cm.

References

1. **Odinets, S.S. & Toplin, G.E.** (1977) *Means of torque measurement.* M.: Mashinostroenie (in Russian).
2. **Gaponov, V.L., Gurinov, A.S. & Dudnik, V.V.** (2012) Measurement of torque on rotating shafts, *Vestnik Donskogo gosudarstvennogo tekhnicheskogo universiteta,* (1-2), pp. 25-32 (in Russian).
3. **Okopny, Y.A., Radin, V.P. & Chirkov V.P.** (2001) *Mechanics of Materials and Structures.* Moscow: Mashinostroenie (in Russian).
4. **Vasiliev, V.V., Khokhryakov, B.G., Bakalov, S.I., Seleznev, G.N. & Pisanko, E.D.** (2004) *Torque measurement device (variants).* 42312 RF (in Russian).
5. **Velikotny, M.A. & Kaufeldt, A.K.** (2000) *Method of torque measurement and device for its implementation.* 2152011 RF (in Russian).
6. **Kasatkin, A.G.** (2005) *Basic processes and apparatuses of chemical technology: textbook for universities.* Moscow: Al'yans (in Russian).
7. **Braginsky, L.N., Begachev, V.I. & Barabash, V.M.** (1984) *Stirring in liquid media.* L.: Khimiya (in Russian).
8. **Barabash, V.M. & Zelensky, V.E.** (1997) Stirring of suspensions, *Teoreticheskie osnovy khimicheskoj tekhnologii,* 31(5), pp. 465-473 (in Russian).
9. **Girba, E.A. & Leontiev, V.K.** (2009) *Hydromechanical processes.* Yaroslavl: Izd-vo YSTU (in Russian).
10. **Gelperin, N.I.** (1981) *Basic processes and apparatus of chemical technology. In 2 books.* Moscow: Khimiya (in Russian).

11. **Einstein, V.G. et al.** (2006) *General course of processes and apparatuses of chemical technology. In 2 books, Book 2.* Moscow: Logos: Fizmatkniga, pp. 891-1758 (in Russian).
12. **Planovskiy, A.N., Ramm, V.M. & Kagan, S.Z.** (1968) *Processes and apparatuses of chemical technology: textbook for students of technical schools.* Moscow: Khimiya (in Russian).
13. **Pavlov, K.F., Romankov, P.G. & Noskov, A.A.** (2005) *Cases and Tasks on the Course of Processes and Apparatuses of Chemical Technology*. Moscow: OOO TID "Al'yans" (in Russian).
14. **Leontiev, V.K. & Korableva, O.N.** (2015) Development of a combined stirrer for mixing viscous media, *Khimicheskoe i neftegazovoe mashinostroenie,* (5), pp. 13-14 (in Russian).
15. **Solomakha, G.P. & Tarasova, T.A.** (1998) Mass transfer scaling in gas-liquid systems in apparatuses with mechanical stirring, *Teoreticheskie osnovy khimicheskoj tekhnologii,* 32(5), pp. 502-506 (in Russian).
16. **Karpushkin, S.V., Krasnyansky, M.N. & Borisenko, A.B.** (2009) *Calculations and selection of mechanical stirring devices of vertical tank apparatuses*. Tambov: Izd-vo Tamb. gos. tekhn. un-ta (in Russian).

Received 26.12.2023
Approved 16.04.2024
Accepted 22.05.2024