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Investigation of the in-cylinder swirl flow measurement methods and comparison between them in a cylinder head

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ABSTRACT

In the design of the intake port of an internal combustion engine, investigation of the flow coefficient and the swirl ratio is important, simultaneously. They are effective on the volumetric efficiency and combustion efficiency, respectively. Steady flow testing of cylinder heads is one of the methods to measure the flow coefficient and the swirl ratio. In this study, at first, two different methods of swirl measurement are introduced and governing equations is presented. In the following, experimental tests with both methods are performed on the cylinder head and the results of them are investigated. Swirl measurement consist measurement of the rotational speed of paddle wheel or the torque is applied to a honeycomb to take into account the swirl ratio. The paddle wheel mechanism gives lower measured swirl ratio.

1) Introduction

A deep knowledge of the intake and exhaust processes is fundamental to design and optimize modern internal combustion engines. The development of efficient intake and exhaust systems, in fact, plays a key role both in reducing exhaust emissions and fuel consumptions and in improving the performances of actual engines [1, 2].

In-cylinder charge motion has been receiving increasing attention since the introduction of new technologies such as gasoline direct injection or homogeneous charge compression ignition. Therefore, understanding the dynamics of the in-cylinder flow structures is the first step to control fuel stratification, turbulence, and heat transfer efficiently.

An air flowbench (steady flow test) is essentially a device used to measure the resistance of a test piece (such as the cylinder head, manifold, carburetor, throttle body, exhaust systems, etc.) against air flow [3, 4]. In addition, it is easy to implement and is considered as a low-cost option to estimate the ability of the cylinder head to convert the linear motion of the inlet flow to rotational motion including swirl and tumble flow (Figure 1). It is due to these features that currently such tests are being widely used to estimate the effects of geometric changes on the cylinder head and the inlet port with the aim of comparing and thus improving engine performance.

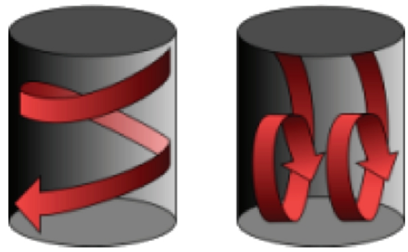


Figure 1: Swirl and tumble in the engine cylinder

Although considerable efforts have been made by researchers to explore the most effective methodology for steady flow tests, there are substantial diversities in the definitions of the technical terms and the techniques used in the existing experiments [4,5] and thus the configurations of the flow bench vary considerably from user to user.

The absence of a standard methodology has obviously raised difficulties in the interpretation of the available data and has posed an obstacle in drawing comparisons between the intake flows characterized by different engine groups [6].

Therefore, it is important to report not only the test results but also the test conditions [7–9].

The experimental techniques, their implications, and the important technical issues involved in the steady flow bench test have been discussed in the early works [10–12].

Fitzgeorge and Allison [13] measured swirl speed using a two-bladed impeller inside a flow rig cylinder. They adjusted the axial distance between the impeller and engine head and found the impeller speed was a maximum when this distance was 1.4 times the cylinder bore diameter. They also used the steady swirl results to try to predict the swirl in an actual engine. Jones [14] measured swirl speed using a straight-bladed anemometer inside the flow rig cylinder and Watts and Scott [15] used a rectangular-shaped vane in their flow rig cylinder and noted the form of the vane had little influence on the measured swirl. Tindal and Williams [16] studied the air flow patterns in a steady-flow rig using light paper flags and a vane anemometer to measure swirl speed. They simulated the presence of a piston in the cylinder by inserting a restrictor plate into the flow rig liner at two bore diameters away from the cylinder head and found that it caused the axial velocity to assume a more regular pattern, which resulted in an increase in measured swirl. Tippelmann [17] set forth the idea of using an impulse-type swirl meter with a flow straightener that converted the angular momentum into a measurable torque. Uzkan et al. [18] described their impulse-type meter having a honeycomb with small cells and large aspect ratio capable of straightening the swirling flow completely. They also note that the honeycomb should not be inserted into the rig cylinder (as in references [17] and [19]), but should lie below it with a larger diameter to eliminate air blow-by. Swirl measurements were made using different head-to-honeycomb distances. A monotonic decrease in measured torque with increasing distance was observed and attributed to cylinder wall friction. They estimated the rate at which the angular momentum decays is on the order of 10 per cent per cylinder diameter of axial distance.

Finally, the literature appears to lack a comprehensive study of the effect of the various measurement devices on the steady flow test results. In this regard, the current paper presents and discusses the effect of swirl measurement methods to the swirl intensity. This study is expected to be of much application to engineers working on the development of engine cylinder heads, particularly those involved in the steady flow tests.

2) Experimental test

The experimental set up is shown in Figure 2 schematically. Special mechanisms and fixtures are used to set valves lift by clock (1). In standard tests on engines with four valves per cylinder, inlet or outlet valves are open simultaneously. Test is performed on a cylinder head (2) and a dummy cylinder (3) is used with a diameter equal to engine bore. Pressure drop is measured with a stagnation pressure gauge (4) relative to atmospheric pressure. A manometer (7) is used to determine the pressure drop in orifice (8) and consequently to measure the volume flow rate. Desired differential pressures are supplied with a bypass valve (10) and air flow temperature is measured using a temperature gauge (11) for air mass flow rate correction. Swirl meter (12) measures tumble and/or swirl intensity, based on its orientation.

The fan (13) is used to suck air from ambient to simulate actual state in the engine.

If swirl meter is placed in the orientation shown in Figure 2 with the adaptor and the air box, it will measure tumble intensity but if it is placed under dummy cylinder (Figure 3), it can measure swirl intensity [20].

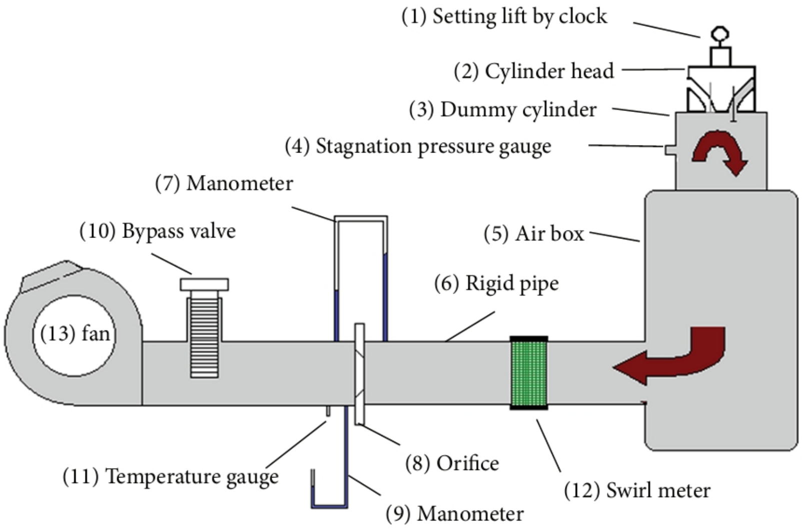
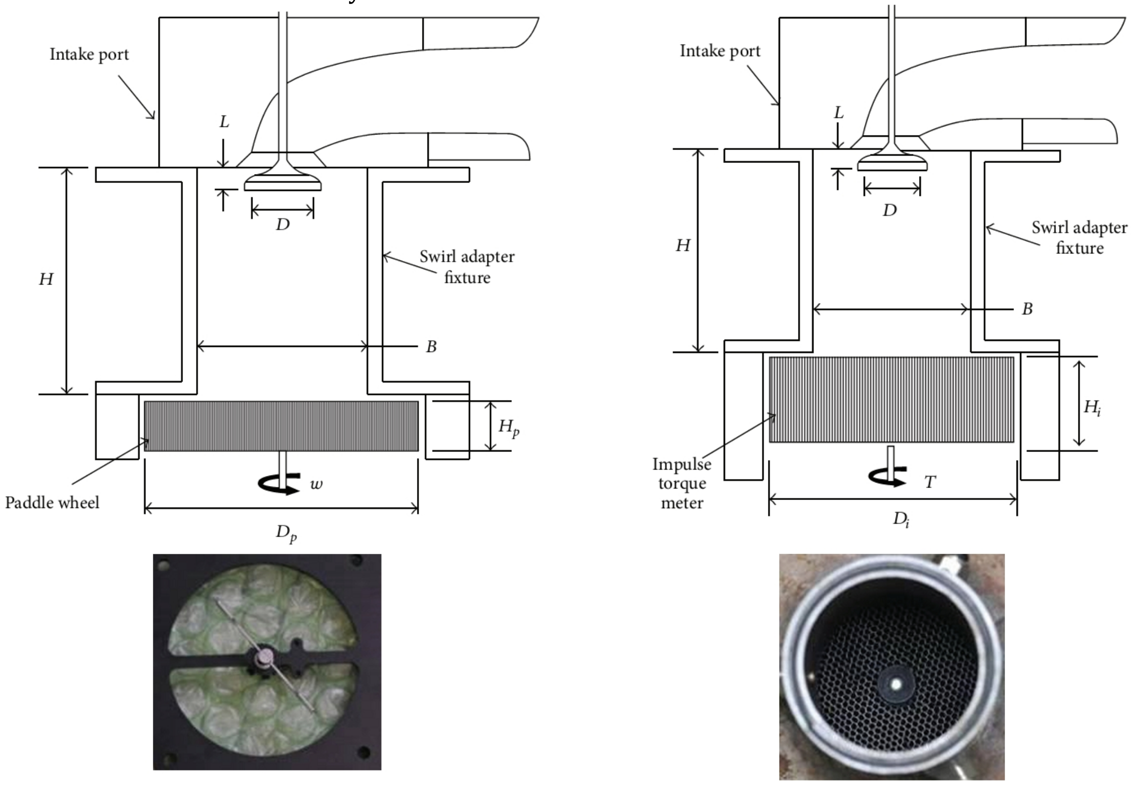


Figure 2: Schematic diagram of the flow bench

Generally, swirl meter measures rotational speed of paddle wheel (because of inlet air flow) as intensity of swirl or tumble (Figure 3a), or as shown in Figure 3b a torque can be applied from the air to a honeycomb to take into account the intensity of the swirl or tumble. In our research honeycomb type is used and an adaptor is used to measure tumble. All of the dimensions in Figure 3 are standardized, based on the engine geometry.



(a) (b)

Figure 3: Swirl meter types: (a) rotational speed measurement and (b) torque measurement [21]

The standard test for inlet port consists of measuring the flow coefficient, swirl and tumble intensities for different valve lift. In this test, after applying the desired differential pressure, the valves lift is set at certain level (Figure 4).

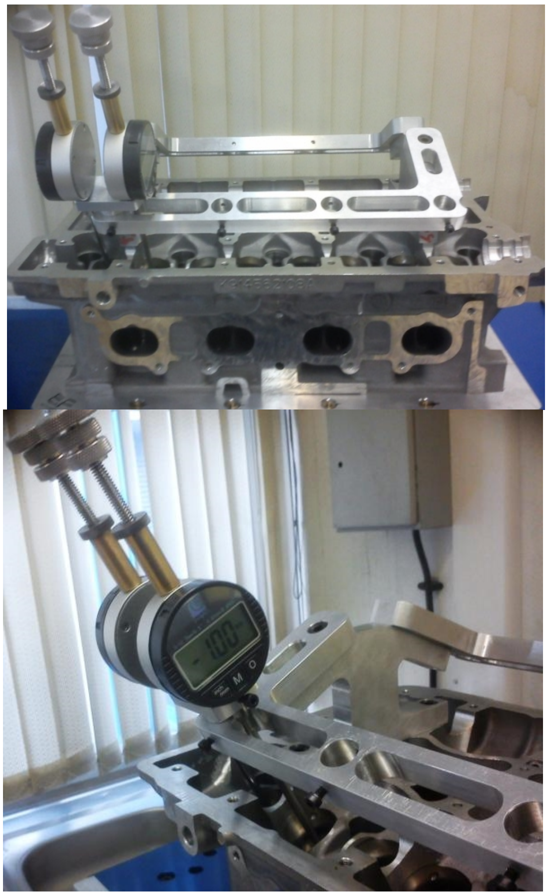


Figure 4: Valve lift adjustment by the relevant fixtures and dial indicator in the flowbench [22]

The test is performed on the cylinder head of a 4-valve spark ignition engine. The engine specifications are given in Table 1.

The reference test used for the purpose of this study is of the following features:

(1) 50 cm-H_2O differential pressure;

(2) inlet flow temperature = 30°C;

(3) volume flow rate measured by the orifice, in the range of 20–71 liters per second;

(4) symmetric intake valve lifting from 1mm to 9mm.

Table 1: Engine specification

Bore (mm)	78.6
Stroke (mm)	85
Displacement (cc)	1650
Inlet port diameter(mm)	26
Inlet valve	
Diameter (mm)	30.6
Stem diameter (mm)	6
Maximum lift (mm)	10
Seat angle (deg.)	44.5
Inclination (deg.)	26

Dimensions in Figure 3 is according to Table 2.

Table 2: The adaptor dimensions based on Figure 4

Parameter	Dimensions (mm)
B	83
H	124.5
D	30.6
L_{max}	8
D_p	132
H_p	15.9
D_l	165

3) Flow Parameters

The flow parameters that will be used to characterize the engine heads are the flow coefficient, C_f and the swirl coefficient, C_s. The flow and swirl coefficients are measured at discrete valve lifts over the range of the cam profile, and are reported as a function of L, where L is the valve lift. The flow coefficient is a measure of the actual mass flow rate to a theoretical mass flow rate and is defined as

$$C_f = \frac{\dot{m}}{\rho V_B A_{ref}} \tag{1}$$

where $\dot{m}$ is the air mass flow rate, ρ is the upstream air density, A_{ref} is the cylinder bore, and V_B is the Bernoulli velocity given by

$$V_B = \sqrt{\frac{2\Delta P}{\rho}} \tag{2}$$

where ΔP is the pressure drop across the test section. The swirl coefficient,C_s is a characteristic non-dimensional rotation rate and is calculated for vane-type meters using

$$C_s = \frac{\omega B}{V_B} \tag{3}$$

where ω is the vane or paddle wheel angular velocity and B is the cylinder bore.

For impulse-type swirl meters, the swirl coefficient is calculated from

$$C_s = \frac{8T}{\dot{m} V_B B} \tag{4}$$

Where T is the torque measured by the meter [21].

4) Results and Discussion

After the test, according to the conditions stated in the previous section, the flow coefficient and the swirl coefficient was extracted. Figure 5 shows a flow coefficient that is a function of the geometry of the port and the inlet valve. In both methods were tried both swirl meter has low resistance and pressure drop of the intake flow is negligible. As is evident in the results due to the honeycomb geometry, the flow is directed and pressure drop is more negligible than paddle wheel. In this case, in the worst case flow coefficient (in high lifts) of about 2% less than using a paddle wheel.

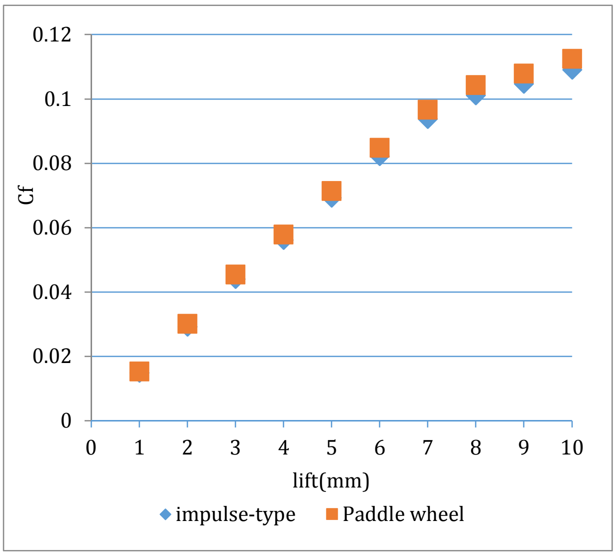


Figure 5: Flow coefficient in two different measurements vs. lift

Rotational speed of paddle wheel in the different lift was measured (Figure 6). Based on Figure 6 rotational speed is ascending in the lifts of 1 to 2 mm and then descending and finally reaches its lowest in the lift 4 mm. After being fixed around the lifts of 4 to 6 mm, in the range of 400 rpm, at the higher lifts rise sharply and with a steep slope to about 1900 rpm is reached.

To investigate the effect of hysteresis, the measurement in decreasing mode of lifts (from the lift 10 to 1 mm) were also conducted. In this mode rotational speed, especially in high lifts, greater values is observed due to arising from the previous test. But this difference is negligible to compare methods. The results of this test are shown in Fig. 6.

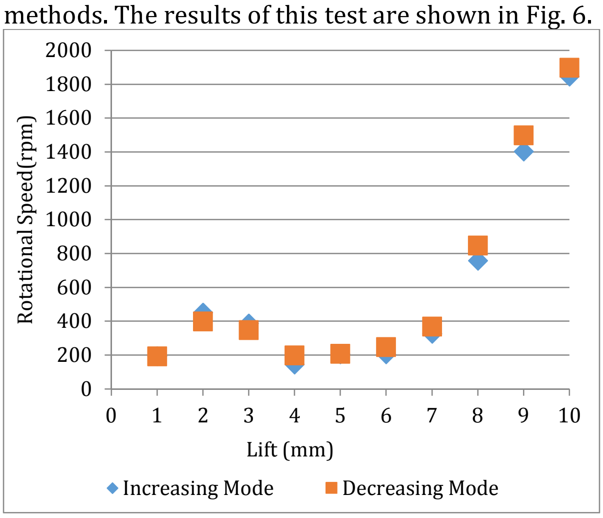


Figure 6: Rotational Speed of Paddle Wheel vs. Lift

Then, the torque applied to the honeycomb geometry also measured and the results were calculated. According to Figure 7, such as the trend of the previous method except that the in the lifts of 2 and 3 mm can be seen. The increasing trend in the swirl flow such as paddle wheel can also be seen here. Torque of impulse type swirl meter in the lift of 7 mm is about $25*10^{-4}$ N.m and after quick jump is reached to $120*10^{-4}$ N.m.

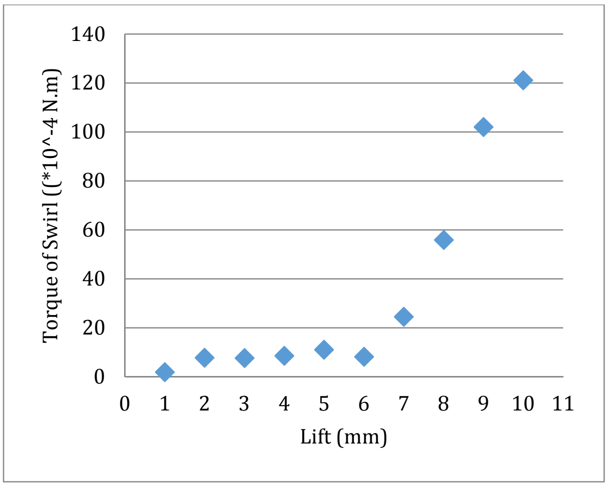


Figure 7: Torque of Impulse-Type swirl meter Vs. Lift

To compare the numbers obtained from the tests, using the relationships is described in the previous section, swirl coefficient was calculated for both methods. Based on the results are shown in Figure 8, at the low lifts, there is no major difference between swirl coefficients extracted from two methods but the differences is visible at the middle lifts and at the high lifts is maximum. It is 0.6 in paddle wheel method and 0.8 in impulse type. As it is shown in Figure 8 swirl coefficient is measured in paddle wheel method is usually lower than impulse type.

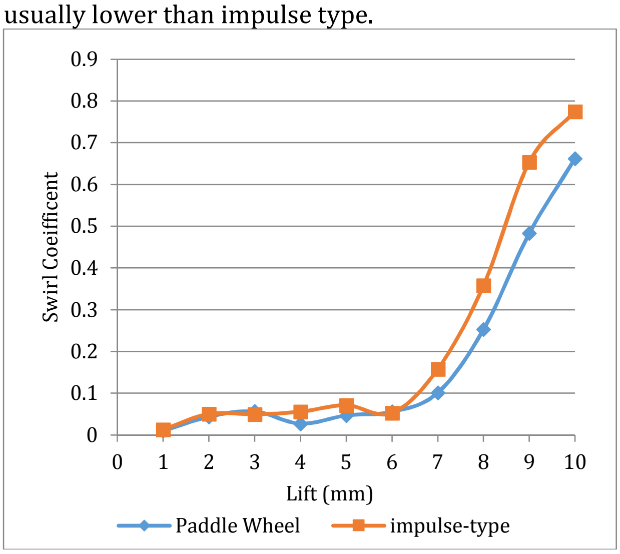


Figure 8: swirl coefficient vs. lift in tow measurement methods

The main reasons of this difference is due to adaptor geometry and measurement methods. In paddle wheel method, because of paddle wheel rotating, friction of air is involved and swirl is measured less than actual manner, in the high lifts, mass flow rate increases and the friction is more effective and this method is more sensitive to disturbance and wake. Also, there is friction between shaft and bearing. In other side, in the impulse type method, the honeycomb is immersed in oil, does not rotate and just measured applied torque. Also this method is less sensitive to disturbance and wake.

5) Conclusion

In this study, at the first two methods in swirl flow measurement is described. Then, on a sample cylinder head, flowbench test was conducted using both methods. As a result, the quantity of flow coefficient is approximately similar in both methods and the difference is less than 2%. So regardless of what way flow coefficient is measured in each cylinder head, this factor is identical and the test reports about this factor is not required to announce the type of measurement. Swirl flow in two method have a same trend but if swirl calculates based on swirl coefficient, results of these two measurement equipment will be different. In the paddle wheel method, the swirl is weaker, especially in the high lifts. So, in use and reporting, type of measurement is important and it must be declared and In fact, there is a need for a correction factor for the comparing and converting. The main factors causing the difference between these two methods are air friction, bearing friction and sensitivity to disturbance and wake.

Acknowledgment

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Nomenclature

A_v	Reference Area
B	swirl adapter fixture bore
C_f	flow coefficient
L	Valve lift
$\dot{m}$	mass flowrate of air
C_s	swirl coefficient
d_I	diameter of impulse torque meter honeycomb cells
d_p	diameter of paddle meter honeycomb cells
H	height of swirl adapter fixture
H_I	height of impulse torque meter honey-comb flow rectifier
H_P	height of paddle meter paddle wheel
L_{max}	peak valve lift
P	pressure
T	measured torque
V_B	Bernoulli velocity
ρ	Air density
ω	paddle wheel angular velocity

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بررسی روش‌های اندازه‌گیری جریان‌های گردبادی داخل استوانه و مقایسه آن‌ها در یک بستار نمونه

ابوالفضل محمدابراهیم[1*]

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نویسندۀ مسئول

چکیده

در طراحی راهگاه ورودی جریان در موتورهای احتراق داخلی، علاوه بر ضریب جریان که رابطه مستقیم با بازده تنفسی موتور دارد، شدت جریان های گردبادی نیز که بر بازده احتراق تأثیرگذار است مورد توجه قرار می گیرد. یکی از روش های تجربی بررسی مقدار ضریب جریان و نسبت جریان گردبادی راهگاه ورودی، آزمون میز جریان است. در این مطالعه، در ابتدا دو روش اصلی اندازه گیری شدت جریان گردبادی معرفی شده و روابط حاکم بر آنها ارائه و مقایسه می گردد. در ادامه آزمون های تجربی با استفاده از این دو روش برای یک بستار نمونه انجام گرفته و نتایج آنها مورد بررسی و مقایسه قرار می گیرند. این دو روش که در مراکز تحقیقاتی مختلف مورد استفاده قرار می گیرند شامل اندازه گیری سرعت دورانی جریان گردبادی با استفاده از چرخ پارویی و اندازه گیری گشتاور اعمالی جریان گردبادی با استفاده از یک هندسه لانه زنبوری می باشد. با انجام این مقایسه، امکان بررسی و مقایسه اطلاعات ارائه شده توسط محققان مختلف که با یکی از روشهای مذکور انجام گرفته است، فراهم خواهد آمد. در ادامه می توان با انجام آزمون های بیشتر و با استفاده از ضرایب تصحیح مناسب، نتایج این دو روش را به یکدیگر تبدیل کرد. نتایج نشان می دهد که به علت ماهیت روش اندازه گیری، نسبت جریان گردبادی محاسبه شده با استفاده از چرخ پارویی اعداد کوچکتری را نتیجه می دهد.

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