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Application Possibilities of Rotary Pneumatic Drives Using

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Abstract This paper considers the analysis procedure for the design and dimensioning of rotary air motor with regard to its possible an his application intended.

Keywords: *pneumatic air motor, calculation of basic parameters, drive selection, application use*

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1. Introduction

In technical practice it occurs frequently be used to drive a device for continuous operation the rotary actuators that fulfill the some specific criteria (eg. Installations in explosive atmosphere requiring the use only components that fulfill the ATEX Directive).

Electric synchronous or asynchronous motors commonly used for example. to drive the conveyors of various kinds are practically unusable.

Solution to the problem provides the use of a pneumatic rotary actuator which, thanks to its characteristics, it meets the criteria of use.

Pneumatic air motors in certain properties surpass electric drives. Among the biggest advantages of rotary actuators includes [1,3,9]:

- **the compactness:** occupy a only about 1/3 the build-size of an equally efficient electric motor;
- **low weight:** their weight represents about 1/5 the weight equally powerful electric motor;
- **nonelectrical sparking:** in general fulfill the ATEX specification (possibility of use in the explosion impending environments);
- **robust design:** long durability and the possibility of use even in extreme conditions;
- **easy maintainability:** relatively easy assembly and installation;
- **overload capability:** high load capacity without the risk of any damage to standstill;
- **easy control:** possibility of step regulation of air pressure or flow control;
- **possibility of simple reversing of rotation:** most of rotary actuators is supplied in versions for use in two directions of rotation.

2. Rotary Air Motor

Rotary air motor is a component of a mechanism that transforms compressed air energy into mechanical rotary motion with unlimited number of revolution (thus differs from so-called oscilating actuators, by their design on the output reaches the a maximum of 360°).

Methods of apportionment from various aspects shown in Figure 1.

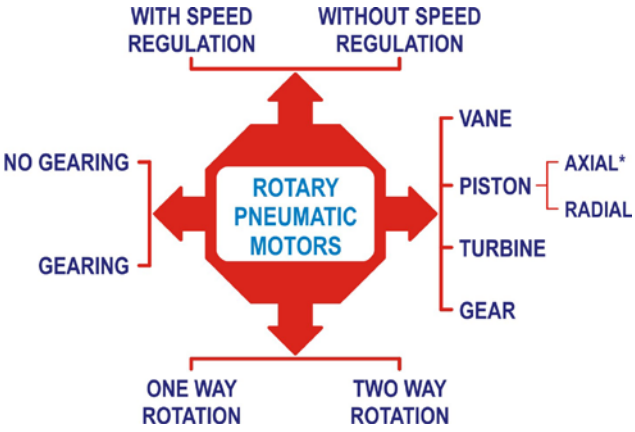

Figure 1. The possibility splitting of rotary air motors

Before applying the rotary pneumatic motor must be carried out process of its selection and dimensioning according to specified boundary conditions.

3. Criteria for Air Motor Selection

The parameters for the air motor selection:

1. the construction design of air motor;
2. used material;
3. direction of rotation;
4. determining working pressure;
5. calculation of required power;
6. determining of the working point (interval);
7. determination of drive control method;
8. assessing of the suitability of oil use;
9. selection of auxiliary equipment;
10. conditions and forms of connection;
11. solving of noise level;
12. durability, reliability and maintenance.

3.1. The Construction Design of Air Motor

There are a number designs of rotary air motors; best known of them are vane, piston, gear and turbine, Figure 2.

3.1.1. Vane Rotary Air Motors

The most commonly used type of rotary air motors. They are produced in two variants: non-expanding type, Figure 2a) and expanding type (incomplete expansion), Figure 2b).

The operating principle is shown in the illustration. As the rotor 2 and the body 3 are positioned eccentrically, centrifugal force or spring force on surface of the body is pressed vane (must be lubricated oil aerosols).

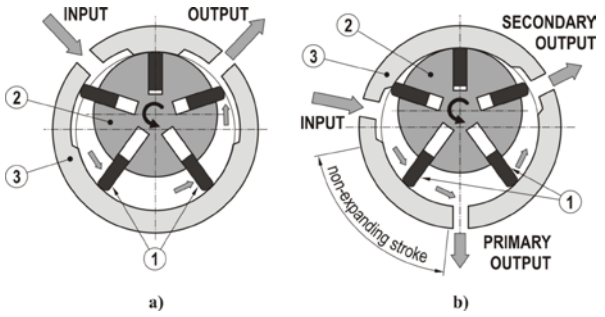

Figure 2. Basic types of vane air motors [4] ***edited by the author***

Maximum of the no-load rotation speed is totaled some 20,000 rev/min, start torque is within the range of 1 to 147 Nm and air consumption (depending on size) is in the range 1.0 to 1.5 I_N/min.

3.1.2. Piston Rotary Air Motors

There are two versions: the axial, Figure 3 a the radial, Figure 4. Both types are characterized in that, in contrast to other design types have the pulsating torque curve and the rotation speed.

Versions with axial piston drive arrangement are relatively rare, although the torque is of all designs is highest.

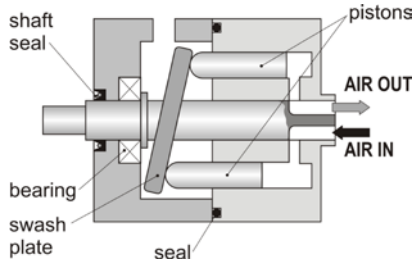

Figure 3. Axial piston air motor [4] ***edited by the author***

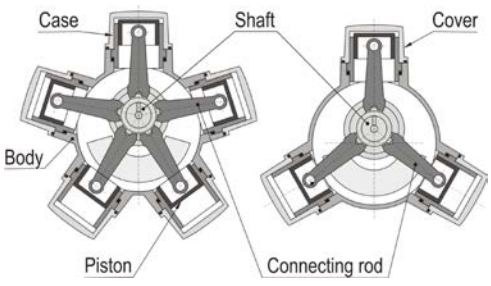

Figure 4. Radial piston air motor [1] ***edited by the author***

Design radial piston arrangement are more common; They are produced in two variants: as a star-arrangement of cylinders (always an odd number) with connecting rod gripping eccentrically mounted on the shaft coupled to the counterweight, Figure 4.

The described system transformation linear movement on rotary is designed centric fit of the drive shaft when called. multi-stroke radial drive, Figure 5.

Speed of rotary piston air motors is in the interval from 1,800 to 8,000 rev/min (no load), the multi-stroke drive is limited to the upper limit of about 900 rev/min.

Torque during engages during a multi-stroke motors is up to 1,100 Nm, other variants of it are significantly lower (only 10 Nm).

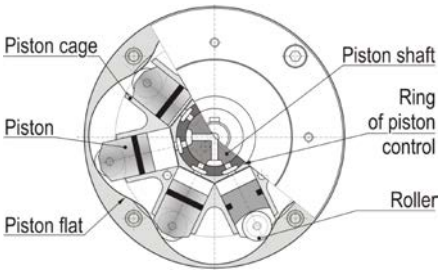

Figure 5. Multi-stroke radial piston air motor [2] ***edited by the author***

All design piston rotary air motors, however, have the efficiency problems, but the consumption of air is relatively small (about 1.1 l_N/min).

3.1.3. Gear Rotary Air Motors

There are two basic designs of gear rotary air motors, Figure 6:

a) standard - with forced circulation (with helical gearing),
b) the Gero type (with planetary circulation).

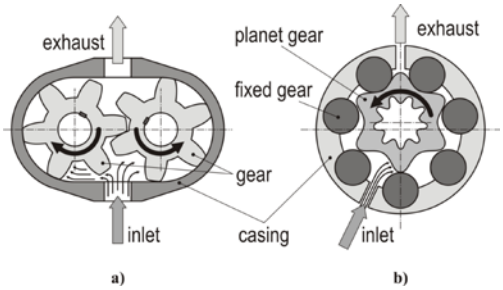

Figure 6. Basic types of gear air motors [4] ***edited by the author***

Starting torque value of 600 Nm attacks, while speed is relatively high (up to 40,000 rev/min, no load). Air consumption is comparable to the vane motors.

3.1.4. Turbine Air Motors

Turbine air motors, Figure 7 as the only of the rotary motors don't uses almost no pressure component of compressed air power, and therefore the starting torque is virtually nil.

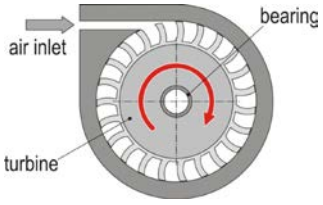

Figure 7. Turbine rotary air motor [1] ***edited by the author***

However, the arrangement of the inlet channel and the engagement of specially shaped blades of the turbine permits the achievement of high values speed: up to 80,000 rev/min without load (in dental drilling machine, Figure 8, the peak rate is up to 120,000 rev/min).

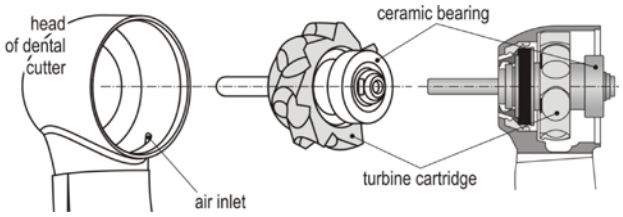

Figure 8. Head of dental drilling machine [8] ***edited by the author***

3.2. Used Material

Material of rotary air drives is highly varied; the bodies of steel (including stainless steel) to the plastic casing.

The use of a particular material in a given application is determined either in the assignment or accordance with generally accepted restriction resulting from the application (eg. The use of stainless steel for the body to drive designed for use in the food industry).

3.3. Direction of Rotation

Rotary pneumatic motors are made in designs with one direction of rotation or with reverse rotation.

If you choose the drive in one direction of rotation, it is necessary to define the direction of rotation already at its ordering. Reverse drive design allows for either connected with the rotation in the clockwise direction or vice versa.

Motor design and the meaning its rotation shows also a pneumatic symbol, Figure 9.

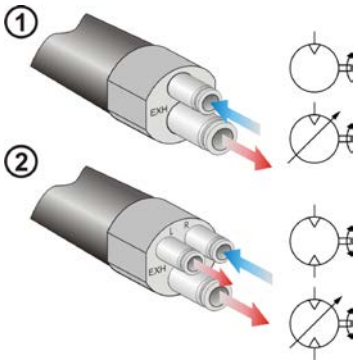

Figure 9. Version of rotation orientation [3] ***edited by the author***

3.4. Determining Working Pressure

A search drive must necessarily endure the pressure range of pressures used in the workshop.

Compressed air distribution systems in the workshop and a method of your cleaning must meet the standards set by the manufacturer of the drive. If needed, must be performed supplement the existing distribution system of compressed air of necessary components, or propose new partial layout of distribution system of compressed air so as to meet the specified requirements.

It is noted that the range of working pressures, Figure 10, as well as their rate of fluctuations affect the correct functioning of drive in operation.

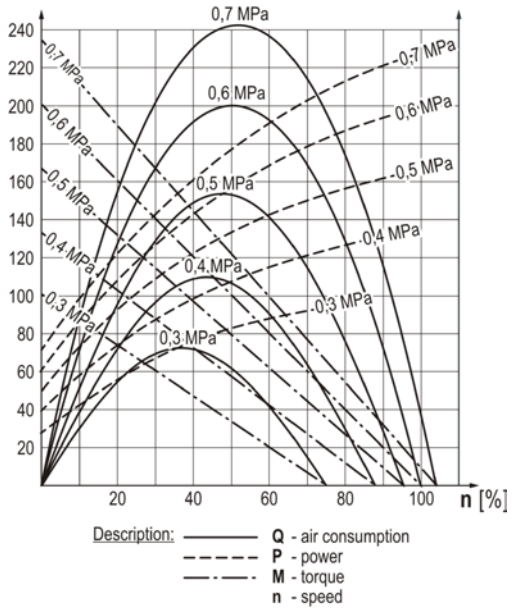

Figure 10. Effect of the operating pressure on the drive parameters [3] ***edited by the author***

3.5. Calculation of Required Power

Calculations for pneumatic rotary actuators are very complicated, because according to the laws of reversible changes in the gas, namely the Boyle-Mariotte law, volume and pressure are in direct relation.

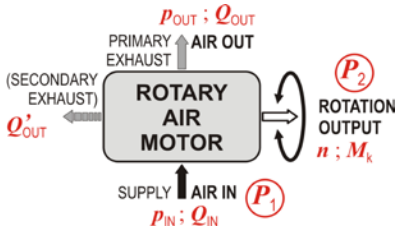

Figure 11. Pressure of the linear pneumatic cylinder

On the linear actuator after the short time is the motor output stabilized (his strength is dependent on the size of the piston surface and pressure). In the case of rotary air motor situation is complicated in that after the start up of the motor is continuous circulation of the compressed air in him and, therefore, during of this period of activity we must consider a pressure drop. Moreover, rotary air motor belong until the dynamic pneumatic mechanisms, thus using in preference the part of kinetic energy as resulting from the Bernoulli equation.

If we use the basic model of the rotary actuator Figure 11 are apparent physical quantities, which will determine by the selection for specific type of application.

On its output power characterized with output speed and torque will participate nominal flow rate and pressure drop of flowing air (similarly to pneumatic valves).

This we must keep in mind when selecting and sizing of the rotary drive. As there are several design variants of rotary motors, are also variants of formulas for their calculation.

In general, however, are motors classified into the rotary actuators with constant and variable flow, and accordingly have a constant or variable course of torque and speed.

It is generally valid relationship between input and output drive power, thus relationship for the calculation of the motor efficiency [9]:

$$\eta = \frac{P_2}{P_1} ...[\%] \quad (1)$$

where P_1 is the motor power input respectively power of the medium (compressed air) and P_2 is power on its output, respectively. output at the shaft.

Substituting for P_1 and P_2:

$$P_1 = Q \cdot \Delta p ...[\mathrm{W}] \quad (2)$$

$$P_2 = 2\pi \cdot n \cdot M_k = \omega \cdot M_k ...[\mathrm{W}] \quad (3)$$

we obtain

$$\eta = \frac{\omega \cdot M_k}{Q \cdot \Delta p} ...[\%] \quad (4)$$

where ω is the angular velocity of the rotating shaft [rad/s]: $\omega = 2\pi \cdot n$, n is the shaft speed [rev/s], M_k is torque at the shaft [Nm], Q is the input flow [m^3/s], Δp is the differnce of pressures between input and otput of motor(pressure drop) [MPa].

If we from equations 1 and 4 determine output power, we get:

$$P_2 = \eta \cdot Q \cdot \Delta p ...[\mathrm{W}] \quad (5)$$

From the above it is clear that the output power of the drive is proportional to the change in flow and pressure between the inlet and the outlet. Then a graph under the various supply pressures could look like in the above figure (Figure 10).

When the motor is stopped, it may be considered 100% efficiency, therefore its maximum starting torque and we can to express from the equality between relations (2) and (3)

$$P_1 = P_2 \quad \Rightarrow \quad Q \cdot \Delta p = \omega \cdot M_k \quad (6)$$

from where then we can determine the value of torque M_k from the relationship

$$M_k = \frac{Q}{\omega} \cdot \Delta p = k_q \cdot \Delta p ... \ [\mathrm{Nm}] \quad (7)$$

where k_q [m^3/rad] is nominal flow of pressure air converted to one radian.

Whereas the internal volume of the rotary air actuator is not always easy to calculate, is determined the resulting flow-through volume by measuring on the motor.

The relationship between flow Q and rotation speed of the output shaft determines the relationship

$$Q = K_q \cdot n ...[\mathrm{m^3/s}] \quad (8)$$

where K_q [m^3/rev] is nominal flow of compressed air converted to one revolution.

3.6. Determining of the Working Point

For correct selection of drive for a specific application it has a decisive influence determination of its working point, respectively. working interval, Figure 12.

Whereas that calculation is not stable of considering air compressibility (resp. are very complicated), this process is carried out by subtracting the value of the graph specified from manufacturer.

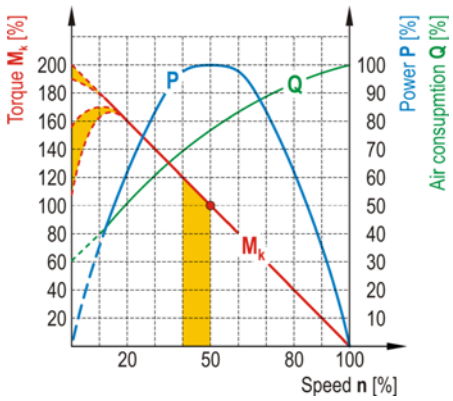

Figure 12. Determination of working poit of air motor [6] ***edited by the author***

This is based on the assumption that operating point will lie in the middle of no-load speed range (nominal speed) and for this speed is read torque. Whereas observance that of the other conditions the power supply in circuit drive for precise speed is not always unequivocally, it sets his interval in the range of 40-50% speed without load.

3.7. Determination of Drive Control Method

Control of rotary motors is relates to the possibility his reversation (appropriate valves) and to the options control its speed, Figure 13.

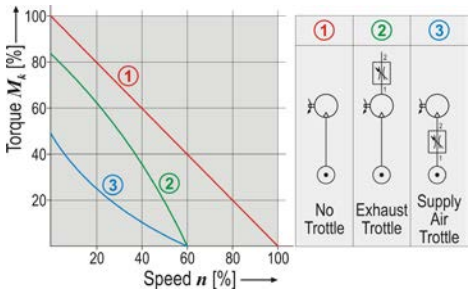

Figure 13. Torque and speed control mode [1] ***edited by the author***

3.8. Assessing of the Suitability of Oil Use

The presence of oil in the supply air is dependent on the design of the drive.

While the vane motors and gear motors strictly oiled air required in the supply air, some embodiments of piston and turbine motors is not required oil. Selection of the actuator in this case must meet the award criteria according to the application (dental drills, food industry, etc.).

3.9. Selection of Auxiliary Equipment

Rotary pneumatic motors are supplied as standard as a basic version or as a version with integrated gearbox, Figure 14.

Gearbox connected in unit with the motor shifts the range of available maximum power and torque to lower speed, Figure 15, what in many cases is with advantage used in application solving.

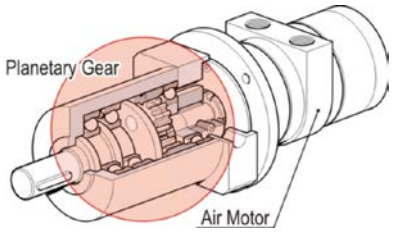

Figure 14. Air motor with integrated gearbox [6] ***edited by the author***

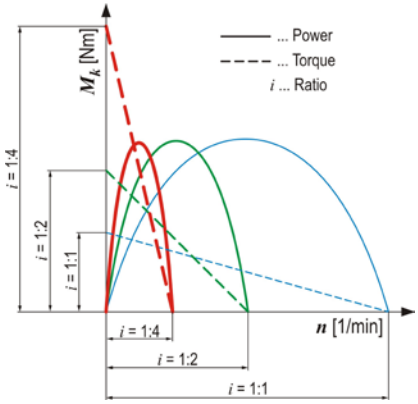

Figure 15. The effect of adding the gearbox to air motor on its characteristics [1] ***edited by the author***

In addition to the of optional equipment the drive with integrated gearbox it can also be used integrated brake, Figure 16.

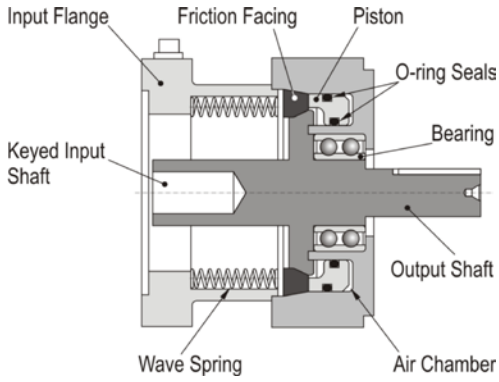

Figure 16. GLOBE BN71 Brake [7] ***edited by the author***

3.10. Conditions and Forms of Connection

For connecting of the air motor to compressed air, is valid all the common rules for the connecting of other pneumatic components. As a rule, are different circuits for drives with one direction of rotation and for the reverse forms.

Connection examples for reverse rotary air motors are in Figure 17. The most commonly used standard push-button or solenoid actuated 2/2 and 3/2 valves (pos. E), or 5/3 valves in designs with the closed (Pos. F), respectively. with deaerated center position (pos. G).

Solving of unit for air treatment (FRL unit: A - filter with condensate separator, B - pressure regulator C - pressure gauge, D - lubricator) installed before the circuit with rotary actuators is enriched by lubricator (pos. D, just in case when for activity of the drive is required).

At reducing of noise which is at activity of the drive generated are applied silencer (pos. J). setting speed of drive solve throttle valve with a check valve (pos. I).

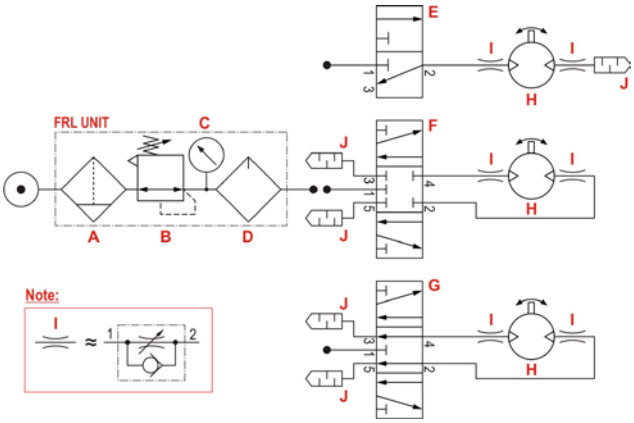

Figure 17. Pneumatic circuits [6] ***edited by the author***

3.11. Solving of Noise Level

The problem with level of noise of rotary pneumatic actuators are known. Its level is dependent both on the type of actuator used (design), as well as the route of noise reduction, Figure 18.

In addition to the location of a suitable silencer the level of the final noise determines also the type of silencer.

About the value of the resulting noise level of the drive ultimately decides putting of his application.

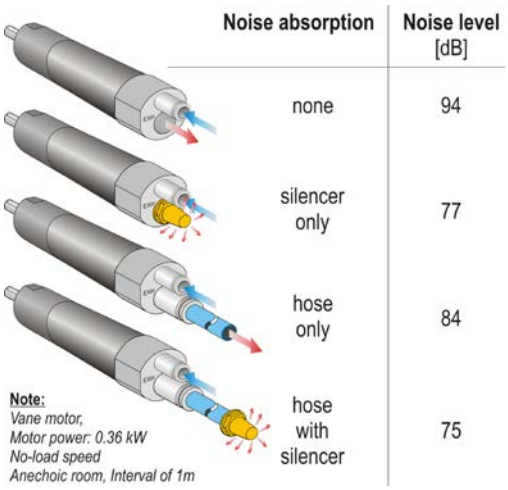

Figure 18. Noise level and it's solutions [3] ***edited by the author***

3.12. Durability, Reliability and Maintenance

Rotary actuators feature considerable sturdiness and in all versions and designs extremely well tolerated congestion.

To ensure high durability and reliability is necessary to observe certain rules:

- is the need to ensure adequate compressed air quality (filtration, drying);
- if you use the lubrication of compressed air , it is necessary to observe the optimum value of oil specified by the manufacturer (the amount of oil is quoted in the number of drops in one cubic meter of compressed air and is not suitable exceed this);
- in the case of using of compressed air free of oil, it is necessary to shorten the maintenance intervals;
- for performing maintenance activities should be to used original service-pack (supplied by the manufacturer of the motor);

- on the drive connection select hose with sufficient internal diameter, is needed a bear in mind the limits on their length (max. 3 m);
- to use the air motor at its nominal speed (working point);
- for the economy of the use of pneumatic rotary motorov it is necessary to monitor the total value of compressed air consumptions and avoid losses caused by the leaks in the circuit (the enjoyment a suitable connecting elements and regular checking joint tightness).

4. Possibility of Applying

As an application areas of deployment of pneumatic rotary actuators can be mentioned:

- The industrial production (as a drive unit of the continuous working devices, eg. drive unit of conveyors);
- hand tools (screwdrivers, torque wrenches, grinders, angle grinders, cutters, milling machine etc.);
- medical care (such as the drive of dental drills or cutters, drives of surgical drills, drives for diagnostic equipment, etc.);
- food industry;
- chemical industry;
- paper industry;
- applications to work under water and others.

Application possibilities using of the air actuators are of two kinds: as stationary and non-stationary.

As a stationary is used the air motors as the power source for various types of conveyors etc..

Non-stationary applications are mainly in the field of hand tools (grinders, drills, Power cutters, milling machines, etc.).

A great role plays the material from which is made the air motor. E.g. for applications in the food industry, paper industry, in chemical, pharmaceutical and medical environment is generally used stainless steel. When applied in medical diagnostics (magnetic resonance imaging, etc.), is like material used the glass ceramic.

In applications with risk of explosion is like material preferentially used stainless steel that complying with the ATEX directive.

Of course, in environments with a undesirable presence of oil mist (eg. dental drills) should be selected variant of air motor that do not require oil to your run.

Obviously, the each application in his the field does not allow any use of the air motor of any design (e.g. for dental drills are used a turbine air motors).

It is for the designer to know the characteristics of different types of air motors and through the boundary conditions for specified applications choose the most suitable variant of the drive.

5. Conclusion

Mainly thanks to their great advantages is the presence of pneumatic rotary actuators in technical practice widespread. There exist operations where the use of another type of drive is virtually impossible.

Application areas for them is a very much many; however, the European market, with certain exceptions, are not as common as it should be (as opposed to the US market).

Maybe it is only in the tradition of using electric rotary actuators and lack of knowledge of the benefits which are by the pneumatic rotary actuators provided.

Acknowledgement

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