1 Introduction

Pneumatics is the discipline that deals with mechanical properties of gases such as pressure and density, and applies the principles to use compressed gas as a source of power to solve engineering problems. The most widely used compressed gas is air, and thus its use has become synonymous with the term pneumatics. Hydraulics is the discipline that deals with the mechanical properties of liquids, and applies the principles to solve engineering problems. Gases and liquids are both fluids as opposed to solids. Pneumatics and hydraulics are similar in many respects and often described by the generic term fluid power.

The use of air as an energy transfer medium can be traced back more than 2000 years, and the varying areas of application reflect the changes in technology since then. The industrial use on a larger scale began 1888 when a 1,500 kW central compressor station was installed in Paris to supply the city with compressed air (Neermann 1989). With the evolution of electric power, this form of energy transfer became obsolete, but the competition between fluid power systems and electric systems is still going on.

Around 1900 the most often used pneumatic components were pneumatic hammers, e.g. in ship yards. As technology evolved, riveting has been replaced by welding and pneumatic hammers are now used mostly on construction sites. Industrial application of pneumatics for automation started around 1950 when the demand for automation in industrial production lines increased and suitable elastomeric materials for valve and piston seals became available.

Many machines require some control logic for safe operation. In the 1960s fluidic elements were developed which use the Coanda effect to give Boolean AND or OR functions. They were working at about 0.3 bar pressure and considered to be the pneumatic equivalent of electronic control (e.g. Kirshner and Katz 1975; Espositio 2000). Many presentations at fluid power conferences discussed the relative merits of fluidic or valve logic. Pneumatic sensors for a number of quantities and even complete flight control system for jet aircraft were developed (Raymond and Chenoweth 1993:117–125). Today, fluidics can only be seen in museums and valve logic is mostly restricted to simple machines that operate in explosive environments. Typically, control is done by a digital computer in form of a programmable logic controller, PLC, with magnetic sensors for piston position and electrically operated valves.

Today, the most important property of the medium air is the simple conversion of pressure to force and translational displacement using a piston in a circular bore. These actuators are of simple design, can be very fast and do not overheat even if stalled indefinitely. The generated forces can be easily controlled by a pressure regulator. The absence of heat generation allows for very compact designs and an excellent ratio of power to weight: a turbine in a hand-held grinder weighs only 185 g and has an output power of 2 kW. Pneumatic cylinders are therefore widely used when masses of up to 20 kg have to be transported over ranges of up to 1 m in a minimum of time.

One of the advantages of fluid power drives is the easy way in which the delivered power can be controlled. A simple variable restriction is sufficient to reduce the power continuously from the nominal value to zero. This is the reason that hydraulic drives were very popular in machine tools because it takes very sophisticated signal processing and power electronics to achieve the same behaviour with electric AC machines which offer otherwise a number of advantages.

Air does not generate sparks, poses no health hazard and can easily be stored. Pneumatic actuators can therefore be used in the explosive environments of chemical plants. If no lubrication is used, air can be vented from the component direct into the atmosphere; a separate return line is not necessary, but some form of silencing is usually applied. Leaks do not cause contamination or electric shocks and are therefore often ignored leading to avoidable losses and high operating costs. A simple bottle is enough to store pneumatic energy for a long time and even under severe temperature conditions. For intermittent use a storage tank can be used and a small compressor suffices for filling.

Atmospheric air is free and this has led to statements that compressed air is a cheap form of energy. However, most of the electric input energy to the compressor is converted to heat, depending on the system between 60 and 90 %. Pneumatic energy is therefore much more expensive than the already expensive electricity. A rule of thumb is that a compressor taking in 11 l/s of free air at atmospheric pressure will require an electric input power of about 4 kW to produce an output pressure of 7 bar (Falkmann 1975b:476). However, in a modern factory the heat from the compressors can be recovered to reduce the cost of compressed air up to 80 % (Ruppelt 2003:489). It is therefore impossible to make general statements about the cost of compressed air or the energy cost of pneumatic tools. Part of the cost disadvantage is offset by the fact that pneumatic components are inexpensive and can operate at a high number of cycles per workday.

The high compressibility of air makes control of actuator velocity very difficult. Due to the low viscosity air can usually not be used to lubricate the machinery it actuates.

The advances in electronics helped to develop control systems for electric drives that made them superior to formerly used fluid power actuators. This technology can also enhance the performance of pneumatic drives. Examples are open or closed-loop controlled cylinders for manufacturing or assembly tasks, pressure controlled chambers in lorry braking circuits or position controlled actuators for process valves.

This book is organised in three parts. The first part consists of chapters 2–7 and gives the theoretical background. Chapter 2 describes properties of compressed air, followed by a short review of thermodynamic processes and some results from fluid mechanics. In Chap. 5 models are given to describe the flow rate characteristics of restrictions, in Chap. 6 several models of long lines are derived. Chapter 7 describes the conversion of electric current to mechanical quantities, like force or displacement.

The second part of this book gives a description of pneumatic components. The standard cylinder which is the most important converter from pressure to force is modelled in Chap. 8. The following chapters describe non-standard linear actuators like bellows and chambers for braking systems in lorries, busses or trains and suspensions in passenger cars, and semi-rotary actuators. Motors and turbines are modelled in Chap. 11. The rest of this part is devoted to valves. Chapter 12 introduces directional control valves which are needed to direct supply pressure to the appropriate actuator ports. Chapter 13 describes shut-off valves. The important class of pressure control valves follows. Flow control valves are presented in Chap. 15 and in the following chapter proportional directional control valves are described.

The third part of this book describes systems, i.e. the combination of components to fulfil a certain task. In Chap. 17 methods to control the stroke-time of a drive are presented followed by analysis and design of position-controllers. In Chap. 19 the use of pneumatic drives in the process industry is described and the last chapter gives an introduction to digital simulation of pneumatic systems.

There are many interesting topics that could not be covered in the book. Foremost, the generation, preparation and transportation of compressed air and some areas of application like pneumatic conveying or vacuum technology. But also for many aspects of circuit design like safety requirements and regulations, minimisation of switching functions or advanced control topics like continuous path control the reader is referred to the appropriate texts.