Chapter 2
Measuring Mass

Abstract Measuring mass was a very important task, essentially due to the trades. In this chapter some ancient device to measure the mass are reported. Examples of balance scales from the Egyptians and of Roman steelyards balances are shown.

Introduction

Measuring mass and force, together with the measuring of the linear dimensions that will be exposed in the next chapter, represent the first step in the developing of science and technology. Examples of balance scales from Mesopotamia and Egypt are dated to the V millennium B.C. but their use became common in nearly all the populations.

Speaking about devices, probably those designed to measure the mass were the first ones since a yarn with some knots to measure a length can not be considered a real device. The input to design mass measuring devices were, quite certainly, the trades.

It is interesting to consider that, by the Egyptians, the balance scales was already considered a symbol of justice, even for after death life. The god Anubis, in fact, was also the guardian of the scale balance that was used to measure the weight the soul; if the soul was not heavier than a feather, she was given to Osiris; otherwise it was eaten by Maat. In Fig. 2.1 is reported an Egyptian paint showing the god Anubis and a balance scale.

Ancient balance scales were built in two shapes: one has two arms having equal length, the other had arms having different lengths; the first will be indicated simply as "balance scale" while the second will be indicated as "pendulum scale".

2.1 The Balance Scale

The word balance (that is similar in many languages) comes from the Latin "bi lanx" that means double pan. The balance scale essentially consists in a couple of pans suspended from a yoke; the latter is suspended in the middle point between the points in which the dishes are suspended. The use is very easy and well-known: the

C. Rossi and F. Russo, *Ancient Engineers' Inventions*,
History of Mechanism and Machine Science 33,
DOI 10.1007/978-3-319-44476-5_2

Fig. 2.1 Balance scale and god Anubis

object that has to be weighed is located on a pan while on the other pan are located weights having known value, until the yoke is horizontal. When the yoke is balanced, since its arms have equal length, the weights (and the masses) on both the pans are equal, hence the object's mass is given by the sum of the known weights on the other pan. Such a type of balance scale is common all-over the world and has been used for thousands of years by a great number of civilizations. In Fig. 2.2 are reported a roman balance scale now at the Museo Nazionale, Naples, Italy (on the left) and a detail of a Roman bas-relief showing a large balance scale.

The mathematic theory of the balance scale is not very simple (and certainly was formulated 1000 years after the first balance scales had been built), but it is possible to briefly summarize the main aspects. The precision of a balance scale depends on the quality of its components (mainly the yoke and the suspension pins) and the

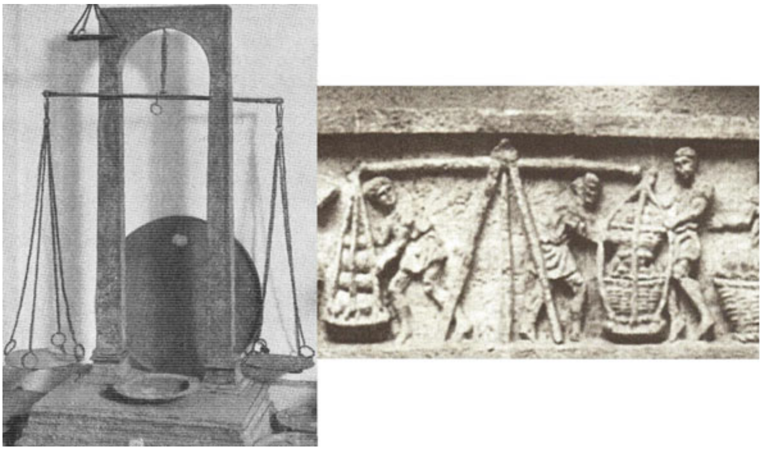

Fig. 2.2 Roman balance scales

accuracy of the weights; the sensibility mainly depends on the yoke's weight and length hence on the balance size. For a thousands of years balance scales have been built in a wide range of sizes, the big ones to measure the mass of large objects and the small ones to compare the weight (hence the value) of the coins.

2.2 The Steelyard Balance

The steelyard is also known as Roman balance because it was invented by the Romans around the 4th century B.C. and was called "statera". In about the same period, about 3th century B.C., similar devices appeared in China. The working principle is shown in Fig. 2.3.

The steelyard has two arms having different lengths; to the shorter one is linked a pan on which is located the unknown mass W, a known (and calibrated) counter-weight R can slide on the longer arm that is graduated. When hung from the hook H, obviously the equilibrium is reached if both the momentums of W and R are equal respect the pivot of the suspension hook H:

$$W \cdot a = R \cdot b \Rightarrow W = a \cdot R/b \tag{2.1}$$

Since the counterweight R and the arm's length a are constant, W is a function only of the distance b. To weigh an object it is only necessary to move the counterweight R along the arm till the steelyard is horizontal and then to read the weight on the graduation of the long arm. This device is generally less precise than the balance scale but it is very easy to handle and to carry since it does not require a set of known weights.

A very good description of the steelyard is given by Marcus Vitruvius Pollio (1st century B.C.), who was a Roman writer, architect and military engineer that will be widely mentioned in the following chapters of this book, in his famous

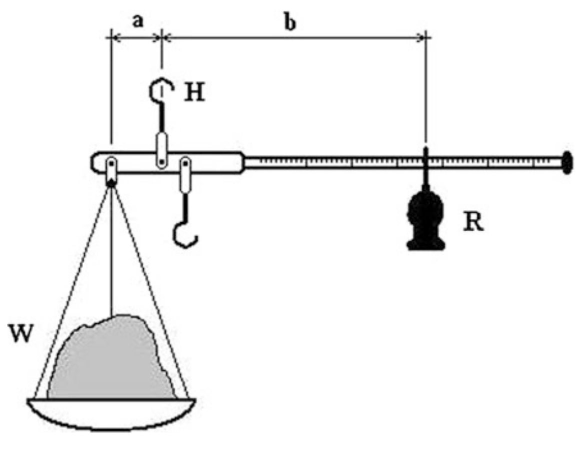

Fig. 2.3 Scheme of a steelyard balance

treatise “De Achitectura”. It is interesting that Vitruvius, in his description, uses the term “momentum” with the same meaning of the English word in mechanics.

In Fig. 2.4 is reported an ancient steelyard found at Hercolaneum.

A later description of the steelyard is given by Saint Isidore of Seville (Spanish name: San Isidro or San Isidoro de Sevilla, Latin name: Isidorus Hispalensis ~560–636 B.C.) who was Archbishop of Seville and one of the most educated man of that age; he wrote about liberal arts, law, medicine, natural science, theology. In his treatise “De ponderibus et mensuris” (On the weights and measures), he calls statera the scale balance while the steelyard is called “Campana” after the name of the Italian region Campania where, according to him, the first example of this device was found. Really the word “campana” does not appear in the classic Latin literature but only in the later one.

Observations

Balance scales having, substantially, the same shape of those built thousands of years ago, have been built up until the present day and have been the only device to make accurate measures of weight till the very recent invention of electronic dynamometers. Some of those balance scales, built for laboratory use, have a sensibility of 0.1 mg in a range from 0 to 200 g.

Balance scales and steelyard measure the mass because the measurement is made by comparing the gravitational force acting on two masses; the authors think that ancient force measuring devices could have existed but they have not found any proof of this.

Also steelyards are still used; until a few years ago these devices were used in most country markets. Some modern steelyards are still built in small size to weigh the gunpowder charge to load the cartridges; these devices generally have a sensibility of 0.1 grain (=0.0065 g).

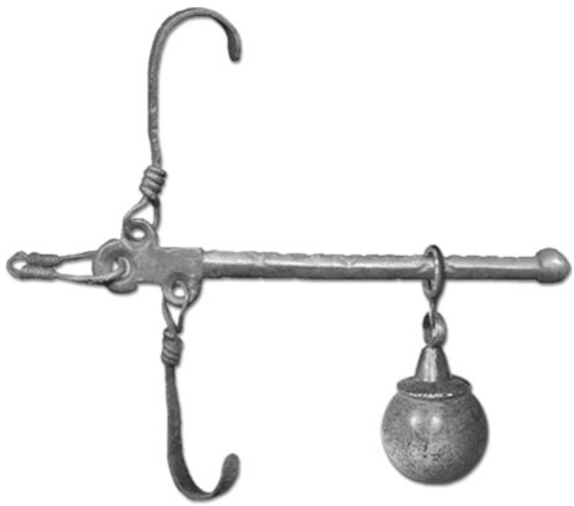

Fig. 2.4 Steelyard found at Hercolaneum

It is interesting to report a legend, told by Vitruvius, that demonstrates that, in ancient times, also the concepts of specific weight and density were well-known: when Hieron I became tyrant of Syracuse in Sicily (from 278 to 267 B.C.), he wanted to offer a votive crown made of solid gold to a temple; so, he gave the necessary amount of gold to a goldsmith. Once the crown was made, Hieron was doubtful that the goldsmith could have made the crown by substituting some gold with silver and so asked Archimedes, the well-known ancient scientist (Syracuse ~287–212 B.C.), to discover whether the crown had been made only by gold or not. Archimedes operated as follows:

(1) He weighed the crown;
(2) then he got an equal mass of gold and an equal mass of silver;
(3) finally, he took a container full of water, put the gold mass in it and measured the water that spurted from the container that obviously represents the volume of that mass of gold.
(4) The same was done with the silver mass and with the crown.

The volume of water that spurted from the container when the crown was immerged was lower than the water that spurted with the silver mass but more than the water that spurted with the gold mass; from this Archimedes concluded that the crown was not made of pure gold but of a gold with silver alloy.

Vitruvius does not tell us if Archimedes computed the gold amount that was substituted by silver but, on the bases of the described procedure the computation is very easy:

$$\frac{Gold\ mass}{Silver\ mass} = \frac{Silver\ volume - Crown\ volume}{Crown\ volume - Gold\ volume} \tag{2.2}$$

A very simple equation that that such a mathematician, as Archimedes was, could have probably used.

According to the procedure described by Vitruvius, Archimedes did not use any balance scale.

The same legend was told later but the procedure credited to Archimedes was different: on one of the pans of a balance scale was put the crown and on the other pan some gold having the same mass of the crown; in this way, the yoke of the balance was obviously horizontal. Then the balance scale was put into water: since the pan containing the pure gold went down, Archimedes concluded that the crown was not made by pure gold but contained silver.

The second procedure is more plausible because to a certain amount of silver in the crown could have corresponded to a very little difference of volume that could have been hardly measured in that age. In any case, both procedures show that those concepts were known by scientists and engineers in those ages.

http://www.springer.com/978-3-319-44475-8

Ancient Engineers' Inventions
Precursors of the Present
Rossi, C.; Russo, F.
2017, XVII, 420 p. 300 illus., 116 illus. in color.,
Hardcover
ISBN: 978-3-319-44475-8