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最新質量計測技術

ADVANCED WEIGHING TECHNOLOGY

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PREFACE

In the last several decades, important progress has been made in weighing technology by introducing loadcells and microprocessors. The implementation of the loadcells and microprocessors has drastically improved the performance of the scale in statics and dynamics. Through the experiences of such implementation, the engineers have realized, more than before, the importance of the dynamics to improve the performance of the scale. This is a book on weighing technology, emphasizing the importance of the theoretical aspect of the dynamics. The authors have worked at different institutes in the field of the technology for more than 35 years, experiencing its drastic change. We wish to present the essence of our experiences to the readers who will work on the weighing technology in the 21st century.

Following is the short description of each chapter of the book:

Chapter 1 presents the basic concepts of weighing. The functions and structures of the scale are considered, through which fundamental structure of the scale and weighing principle are deduced. The difference between the mechanical scale and the electrical and electronic scale is made clear. The features of the scale for industrial use are also considered.

Chapter 2 provides a knowledge, in the minimum, of the statics : the statics of a lever, lever systems, typical mechanical scales, such as a Roberval-type scale and a platform scale, and a double-beam-type loadcell scale.

Chapter 3 is the core of the book, dealing in considerable detail with the dynamics of the scale based on the dynamic model of mass-spring-damper system with Coulomb damping. For clear understanding, the dynamics of various scales, such as a hopper scale, a conveyer belt scale and a weigh feeder, is exemplified. This chapter presumes a reasonable familiarity with the Laplas transformation.

Chapter 4 is used for acquiring an elemental knowledge of representing the digital signal and system, and that of the concept of digital filtering.

Chapter 5 is composed of the materials, most of which have been obtained through the research work carried out by K. Kameoka. Each material contains some interesting phenomena from the viewpoint of dynamics or mathematics. We hope you will enjoy them.

Appendixes A.1 and A.2 provide the tables of Laplas transformation pairs.

ACKNOWLEDGEMETS

It is Wang Dongbao, Former President of China Metrology Publishing House (CMPH), who suggested the idea of publishing a book on weighing technology, placing the emphasis on the dynamics, in details and in three languages ; Japanese, Chinese and English. Without his suggestion and encouragement, such a unique book like this would never have been completed. The authors wish to express the greatest gratitude to Mr. Wang Dongbao.

The authors first completed the manuscript in English, spending considerable amount of time. Then the Japanese translation was done by K. Kameoka .We asked the Chinese translation to Cai Chang Qing, Engineer of National Institute of Metrology (NIM). Owing to her skill as a specialist of mass measurement, clear and correct translation was completed. The word processing and figure drawing work both in Japanese and English versions is due to M. Nakatani in a doctor course, Himeji Institute of Technology (HIT). The authors are pleased to acknowledge the considerable assistance of Ms. Cai Chang Qing and Mr. M. Nakatani.

This book is composed of the contents obtained by refining the ones on which we have lectured about 20 times at the universities, research institutes and companies in three countries ; Japan, China and Korea. The questions and answers at the lectures are effectively reflected in the description of the book. In this connection the authors wish to thank Ishida Co., Ltd. for giving us the chance of lectures seven times.

The authors' first meeting was at the International Symposium on Measurement of Force and Mass (ISMFM '92). For giving us the chance of the happy meeting, we would like to thank Prof. Wang Liji, Former Deputy of NIM, and Dr. C. Maeda, Emeritus Prof. of Osaka Institute of Technology, who were key persons to hold the Symposium. K. Kameoka would also like to express his appreciation to Dr. T. Ono, Emeritus Prof. of Osaka Prefecture University, for continuing guidance and encouragement.

Finally, the authors would like to thank Mr. Ma Chun Liang, President of CMPH, Mr. He Weiren, Deputy Chief-Editor, and Ms. Wang Hong, Editor, for having published the book by their efforts, in time for the beginning of the new century.

Koichi Kameoka (HIT, Japan)
Shi Changyan (NIM, China)

November, 2000

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CHAPTER 1

FUNCTIONS AND STRUCTURES OF SCALES

1.1 BASIC STRUCTURE AND WEIGHING PRINCIPLE

Two different types of the mechanical scale are illustrated in Fig. 1.1. What are the common features to the scales in basic structure and weighing principle?

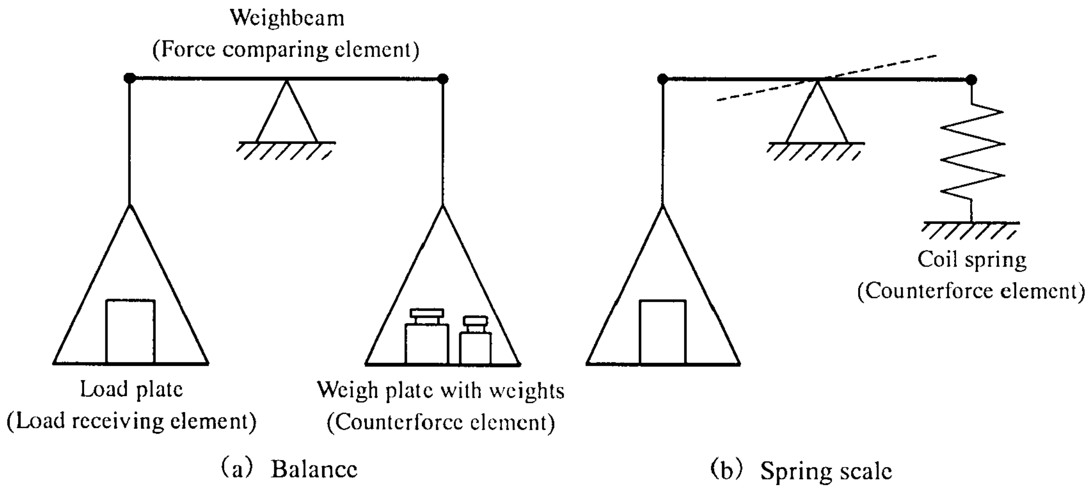


Figure 1.1 Mechanical scale

In the balance or lever scale illustrated in Fig. 1.1(a), the mass of the object to be measured and located at the load plate is compared with the mass of the weights to be located at the weight plate as the moments due to their gravity around the fulcrum by means of the weighbeam. This can be considered a comparison of the force due to the load of object with counterforce due to the weights, both acting on the weighbeam. As for the spring scale illustrated in Fig. 1.1(b), the restoring force due to the elongation of spring is considered the counterforce or resistant.

The above consideration leads us to the recognition that those scales can be divided into three functional elements in common, which are the *load receiving element or load receptor*, the *force comparing element* and the *counterforce element*. The load receiving element, such as a load plate, is a portion of the scale which receives an object to be measured and applies the force caused by the mass of the object to the force comparing element. The counterforce element, such as a weight plate with weights or a spring, is a portion of the scale which develops a counterforce, applying it to the force comparing element. The force comparing element, such as a weighbeam, is a portion of the scale to which the above two forces are applied.

When examining any types of the mechanical scale, we notice they have the above structure in common. Then, the structure can be regarded as the *basic structure of scales*. Furthermore, *the measurement is based on the equilibrium in the force due to the mass of an object and the counterforce developed in a counterforce element*. Therefore, the application of the equilibrium in forces can be regarded as the *weighing principle of scales*. The modern technological development enables us to apply not only the static equilibrium but also the dynamic equilibrium in forces for mass measurement.

The load transmitting levers should be included in the load receiving element. For the hopper scale whose hopper is directly supported by loadcells, we should regard it as a case that the force comparing element is omitted.

In the balance or lever scale, the measured value can be obtained from the weight change in the counterforce element. In the spring scale the measured value can be obtained from the elongation change of the spring as a counterforce element. Generally, the measured value in the mechanical scale can be obtained by using some quantity changes developed in the counterforce element.

1.2 SYSTEM CONFIGURATION OF ELECTRICAL AND ELECTRONIC SCALES

A *mechanical scale* is a scale in which all functions including display function are realized by mechanical means. On the other hand, an *electrical and electronic scale* is a scale with a transducer which inverts the change developed in the counterforce element to an electrical quantity and with a signal processing device which processes the signal of that electrical quantity to obtain the measured value. Therefore, the electrical and electronic scale are characterized by the *transducers* and *signal processing devices*.

Figure 1.2 shows the basic system configuration of the electrical and electronic scale. The electrical signal converted with the transducer is sent to the signal processing device composing of three functional circuits, which are input circuit, data processing circuit, and output circuit. The input circuit is associated with the circuits, such as filtering, amplifying and A/D converting circuits, which manipulate the output signal from the transducer into a more usable signal for data processing. The data processing circuit is a circuit which processes the input signal to obtain the measured value and the necessary values related to the measurement. The output circuit is a circuit which sends out the

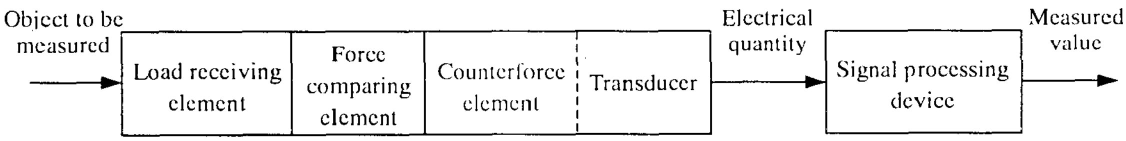


Figure 1.2 Basic system configuration of the electrical and electronic scale

processed results.

According to whether or not they undertake the counterforces as counterforce elements, the transducers are classified into two types which are the noncounterforce-type and the counterforce-type transducer, as shown in Fig. 1.3.

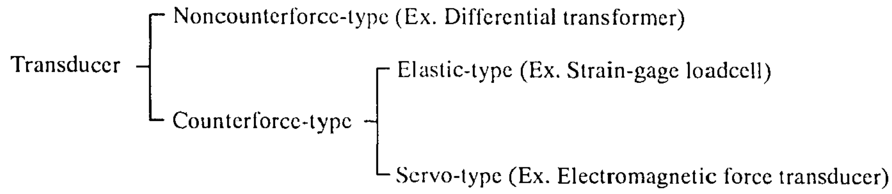


Figure 1.3 Classification of transducers

1.3 FUNCTIONS AND SYSTEM CONFIGURATIONS OF THE SCALES FOR INDUSTRIAL USE

1.3.1 Functional Characteristics and Classification

The scales mainly used for industrial weighing have the following features:

1)The loading on and unloading from the load receiving element are automatic.

2)The determination process of the mass value M of the object by using its weight W is automatic.

The system configuration of such scales is shown in Fig. 1.4. In addition, most of the scales have the following feature:

3)The scale has a function of mass control.

The name and function of representative scales for industrial use are tabulated in Table 1.1.

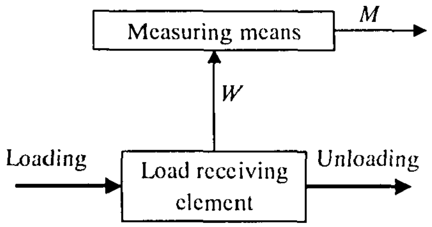


Figure 1.4 System configuration of the scale for industrial use

Table 1.1 Industrial scales and their functions

Name of scale	Function
Belt scale	Mass measurement
Hopper scale	
Hopper scale	Mass measurement & Mass control
Weigh packer	
Weigh feeder	
Check weigher	
Associative weigher	

1.3.2 Control Purpose

Paying attention to the difference of the mass flow of the object being fed onto the load receiving element and the mass flow of the object after the measurement, we could say the purpose of the mass control written in Table 1.1 is the *mass flow control of the object*. From this point of view, the control purpose of the *hopper scale* or the *weigh packer* is to attain an intermittent flow each amount of which is pre-determined. The *associative* (*selective combination*) *weigher* is also regarded as this type of control. The control purpose of the *checkweigher* is to attain the diverging flows according to the pre-determined grades in mass. As for the *weigh feeder*, the purpose is to attain a flow of pre-determined flow rate in mass or to attain a flow the total amount of which coincides with the pre-determined value.

1.3.3 System Configurations

Generally, a *control system* is composed of a *controlled object*, *detecting means*, *controlling means* or *controller* and a *control element* (Fig. 3.23). In the industrial weighing systems, the controlled objects include the feeding devices, distributing devices, and discharging devices, and mass is the *controlled variable*. The system shown in Fig. 1.4 corresponds to the detecting means, and various kinds of actuators are used as the control element.

Figure 1.5 shows the classification, from the view point of the system configuration, of the industrial weighing systems. The system configuration of a *hopper scale* or a *weigh packer* is shown in Fig. 1.5(a). The controlled object is a feeding device, whose typical example is a screw feeder. The control element is a variable speed motor driving the feeder in the case. The hopper corresponds to the load receiving element. The desired value is denoted by the symbol R and the manipulated variable the symbol C. The symbols m and m' represent respectively the states of mass flow and the differences in symbol mean the differences between the two states.

Figure 1.5(b) shows the system configuration of a *weigh feeder*, the typical example of which is a variable speed belt-feeder. The load receiving element is composed of a portion of the belt and the weigh roller(s). The controlled object is the belt-feeder and the control element is the variable speed motor. The total amount of the detected mass is denoted by the symbol Q. Either Q or its derivative Q' is chosen as the controlled variable and the measurement of the belt speed V is needed for obtaining the value Q.

Figure 1.5(c) shows the system configuration of a *checkweigher*. The controlled object is the distributing device and the belt conveyer is normally adopted as the load receiving element.

Figure 1.5(d) shows the system configuration of an *associative* (*selective combination*) *weigher*. Normally, small hoppers are used for the load receiving elements, each of which is equipped with a gate controlled by an actuator. The gates are the controlled objects and the actuators are the control elements.

For the scales shown in Figs. 1.5(a) and 1.5(b), *feedback control* is adopted since the mass flow control has to be carried out while measuring the mass. On the other hand, for the scales shown in Figs. 1.5(c) and 1.5(d), the mass flow control is fundamentally *sequential control* since the control is carried out after the measurement of the mass.

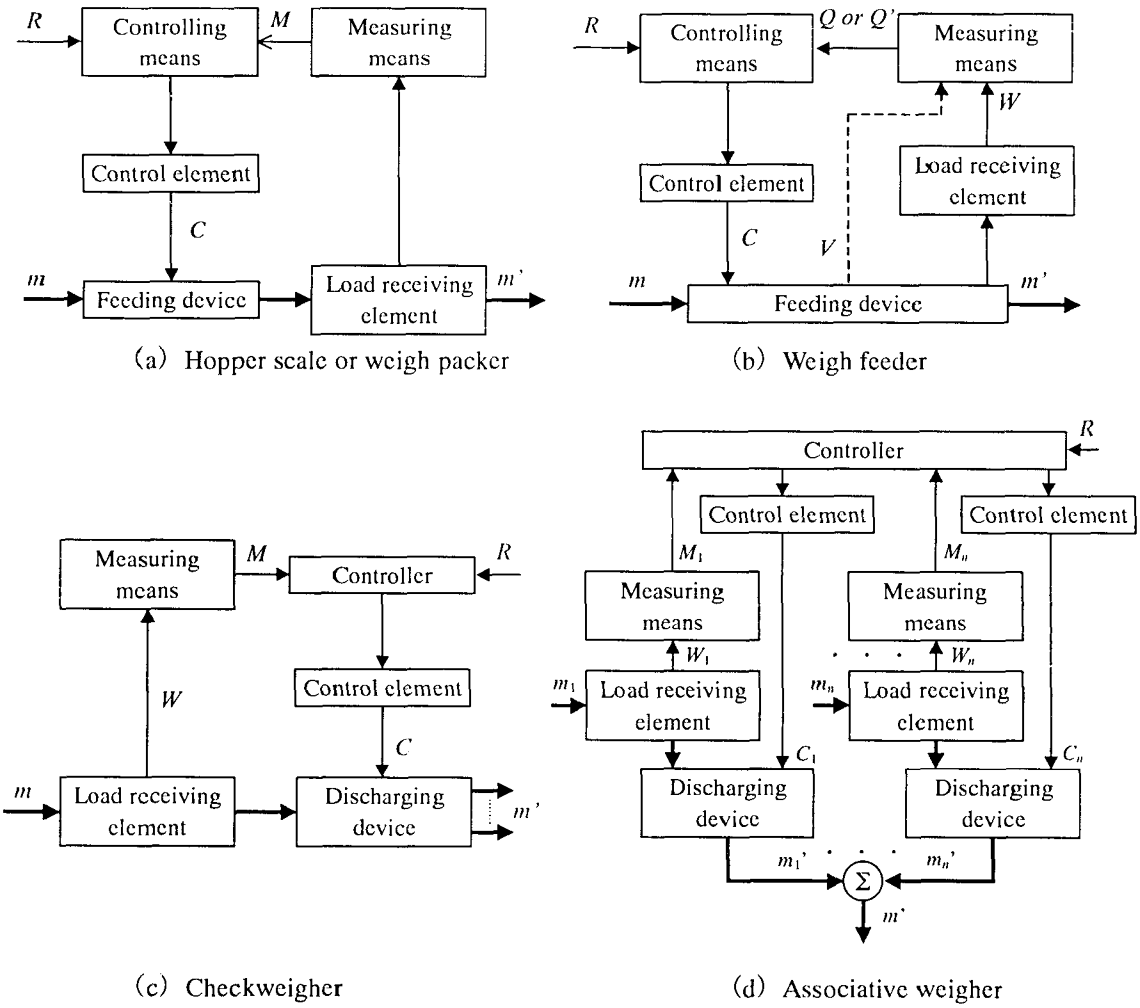


Figure 1.5 Industrial scales with mass control

CHAPTER 2

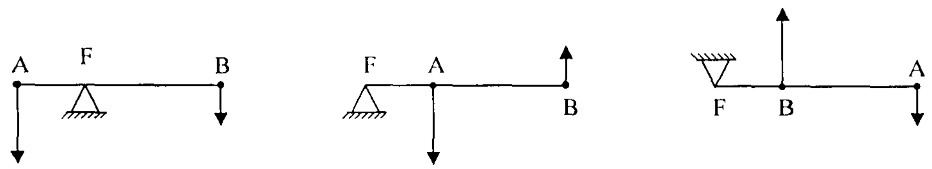
STATICS OF SCALES

2.1 STATICS OF LEVERS

2.1.1 Classification of Levers

A straight lever normally has a *fulcrum pivot*, *load pivot*, and *power pivot*, which is referred to as the *fundamental lever*. Each position of the pivots is referred respectively to as the *fulcrum point*, the *load point*, and the *power point*. The fulcrum point is a point at which a lever is supported and about which it is vibrationable. The load and power points are points at which a load and a counterbalancing force are applied, respectively.

Fundamental levers are classified into three types according to the arrangement of the above three points; the *first-order lever*, the *second-order lever*, and the *third-order lever*. The detail is shown in Fig. 2.1 in which point F is the fulcrum point, point A the load point, and point B the power point, being in a straight line.



(a) First-order lever (b) Second-order lever (c) Third-order lever

Figure 2.1 Classification of levers

The lever (system) is called the *single lever* or the *compound lever* (system) according to the number of connected levers. The single lever is a lever used independently, such as a weigh beam of balance, and the compound lever is a lever system composed of connected levers.

Each number of the fulcrum point, load point, and power point is not limited to one point for one lever. For example, the lever illustrated in Fig. 2.2, which may be regarded as a two-united lever, has two fulcrum points and two load points. A compound lever system including such levers is shown in Fig. 2.3.

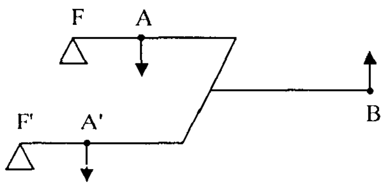


Figure 2.2 A two-united lever

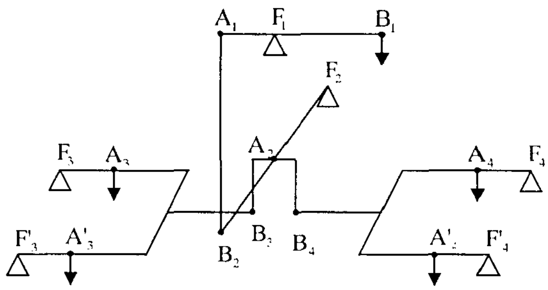


Figure 2.3 Compound lever system

2.1.2 Single Levers

In practical application, there are two cases as to the position of a lever in static equilibrium under loading; the case that the position is always identical with the position under a zero load (Case Ⅰ), and the case that the position varies as the load (Case Ⅱ). We examine the static equilibrium conditions for the above two cases, assuming the lever to be a rigid body.

(1) Static Equilibrium Condition

The necessary and sufficient conditions for the static equilibrium of a single lever are as follows:

$$\sum(\text{forces})=0 \quad \text{and} \quad \sum(\text{moments})=0 \tag{2.1}$$

To examine the static equilibrium conditions for a single lever in Case Ⅰ and Case Ⅱ, we apply the above conditions to the lever whose fulcrum, power, and load points are not in a straight line.

We assume that, when the load is zero, the lever is in static equilibrium under the initial forces, W_0 at point A, P_0 at point B, R_0 at point F, and G at point C (the center of gravity), as shown in Fig. 2.4. We also assume that, when applying the load W and the counterbalancing force P, the lever remains at the same position. The equilibrium conditions before and after the loading are

$$\begin{aligned} &W_0 + P_0 + G + R_0 = 0 \\ &W_0 a + P_0 b + Gc = 0 \end{aligned} \tag{2.2}$$

and

$$\begin{aligned} &(W_0 + W) + (P_0 + P) + G + (R_0 + R) = 0 \\ &(W_0 + W)a + (P_0 + P)b + Gc = 0 \end{aligned} \tag{2.3}$$

where R is the increment of the force at point F.

In Fig. 2.4 we must take the sign into account for the forces and their application points. The downward forces are considered positive and the upward forces negative. The force application points are considered positive when they locate on the load point side in the origin taken at the fulcrum point, and are considered negative when they locate on the power point side. Hence, the counterclockwise moment is positive and the clockwise moment is negative. Inserting Eqs. (2.2) into Eqs. (2.3) reduces to

$$\begin{aligned} &W + P + R = 0 \\ &Wa + Pb = 0 \end{aligned} \tag{2.4}$$

Equations (2.2) and Eqs. (2.4) are the static equilibrium conditions for Case Ⅰ.

Next, let us consider the static equilibrium for Case Ⅱ. In this case, the horizontal distances a, b and c vary since the points A, B and C move as the load W varies. Denoting by a', b' and c' the horizontal distances after the movement, we obtain the static equilibrium conditions as Eqs. (2.2) and the equation in the form of Eqs. (2.3) where a, b and c are replaced by a', b' and c'. No simplified equations corresponding to Eqs. (2.4) can be obtained for Case Ⅱ.

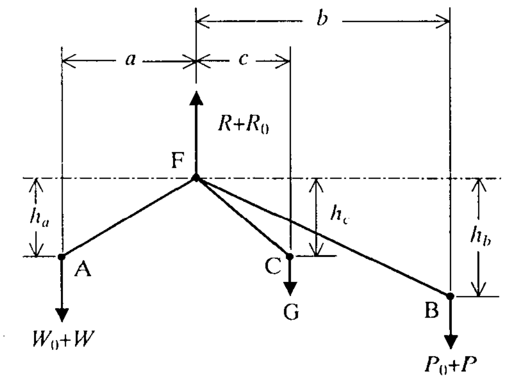


Figure 2.4 Equilibrium conditions for a single lever

(2) Lever Ratio

Lever ratio, denoted by LR, is defined as

$$LR = \frac{FP}{FL} \tag{2.5}$$

where

FP = horizontal distance between fulcrum and power points

FL = horizontal distance between fulcrum and load points

The lever ratio for Case Ⅰ can be written as

$$LR = |b/a| \quad (= \text{constant}) \tag{2.6}$$

Using the second equation of Eqs. (2.4), we obtain

$$|b/a| = |W/P| \tag{2.7}$$

The value $|W/P|$ is known as the *mechanical advantage*. For Case Ⅰ the lever ratio is identical with the mechanical advantage. The lever ratio for Case Ⅱ may be defined as

$$LR = |b'/a'| \tag{2.8}$$

which changes according to the values W and P. In addition the ratio is not identical with the mechanical advantage $|W/P|$.

(3) Sensitivity and Stability

We assume that a new static equilibrium can be attained to a small increment $\Delta\theta$ of the lever angle when a small additional load ΔW is applied. The ratio $\Delta\theta/\Delta W$ is defined as the *sensitivity*. For the case shown in Fig. 2.4, the sensitivity s can be written as

$$s = \frac{\Delta\theta}{\Delta W} = \frac{a}{(W_0+W)h_a + (P_0+P)h_b + Gh_c} \tag{2.9}$$

where (W_0+W) and (P_0+P) are the forces acting at the load and power points, respectively, before the loading of ΔW. The distances h_a, h_b and h_c are of the vertical distances of points A, B and C