普通高等教育“十一五”国家级规划教材
PUTONG GAODENG JIAOYU SHIYIWU GUOJIAJI GUIHUA JIAOCAI

REKONG ZHUANYE YINGYU

热控专业英语

（第二版）

齐宪华　于红霞　主编

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内 容 提 要

本书为普通高等教育"十一五"国家级规划教材。

本书包括33个单元，共六部分，内容涉及自动控制原理、计算机的基本知识、热工检测技术、热工自动控制系统、热工保护、顺序控制、可编程控制等热控专业知识。每个单元的学习材料均由编者从教学、科研、现场实践等多个环节提炼而来，简练生动，单元的长度和设置符合教学要求。每个单元后列出了专业词汇，并对课文的难点内容进行了注释。

本书可作为本科能源动力类和高职高专电力技术类相关专业的专业英语教材，也可作为科技人员和现场运行技术人员的培训教材和自学参考书。

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前　言

本书是为适应高等院校专业英语教学的需要，依据热控专业的教学要求编写的，其主旨是提高学生读译专业英语的能力和水平。

本书包括33个单元，共六部分。涉及自动控制原理、计算机的基本知识、热工检测技术、热工自动控制系统、热工保护、顺序控制、可编程控制等热控专业知识。每个单元后列出了专业词汇，并对课文的难点内容进行了注释。

编者在教学、科研、现场实践等多个环节积累了丰富的材料，每个单元的内容均提炼于此。本书的选材简练生动，单元的长度和设置符合教学要求。

本书由山东电力高等专科学校齐宪华副教授和沈阳工程学院的于红霞老师主编。齐宪华编写了第一部分，第二部分，第三部分的15、19、20单元，第四部分的21～24单元及27单元，第五部分的28～30单元，以及全书的词汇和附录；于红霞编写了16、17、18、25、26、31单元及第六部分；山东鲁能控制工程有限公司王硕参与了图形绘制并承担了部分编写任务。全书由齐宪华统稿。

本书由长沙理工大学潘维加教授和山东大学张承进教授主审。主审老师对本书进行了认真审阅，提出了许多宝贵意见，付出了辛勤的劳动。在此，编者表示衷心的感谢。

本书在收集材料过程中也得到了学校和电厂的大力支持，在此一并表示感谢。

在编写的过程中，由于时间仓促，水平所限，难免有一些疏漏之处，敬请读者指正。

编　者

2010年6月

目　录

Part Ⅰ　Control Principle

Unit One　Introduction to Control Systems

Control Systems

In recent years, automatic control systems have assumed an increasingly important role in the development and advancement of modern civilization and technology. Domestically, automatic controls in heating and air conditioning systems regulate the temperature and the humidity of modern homes for comfortable living. Industrially, automatic control systems are found in numerous applications, such as quality control of manufactured products, automation, machine tool control, modern space technology and weapon systems, computer systems, transportation systems, and robotics. Even such problems as inventory control, social and economic systems control, and environmental and hydrological systems control may be approached from the theory of automatic control.

The basic control system concept may be the simple block diagram shown in Fig. 1. 1. The objective of the system is to control the variable c in a prescribed manner by the actuating signal e through the elements of the control system.

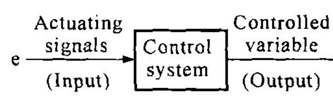

Fig. 1. 1　Basic control system

In more common terms, the controlled variable is the output of the system, and the actuating signal is the input. As a simple example, in the steering control of an automobile, the direction of the two front wheels may be regarded as the controlled variable c, the output. The position of the steering wheel is the input, the actuating signal e. The controlled process or system in this case is composed of the steering mechanisms, including the dynamics of the entire automobile. However, if the objective is to control the speed of the automobile, then the amount of pressure exerted on the accelerator is the actuating signal, with the speed regarded as the controlled variable.

There are many situations where several variables are to be controlled simultaneously by a number of inputs. Such systems are referred to as multivariable systems.

Open-Loop Control Systems (Nonfeedback Systems)

The word automatic implies that there is a certain amount of sophistication in the control system. By automatic, it generally means that the system is usually capable of adapting to a variety of operating conditions and is able to respond to a class of inputs satisfactorily. However, not any type of control system has the automatic feature. Usually, the automatic feature is achieved by feeding the output variable back and comparing it with the command signal. When a system does not have the feedback structure, it is called an open-loop system, which is the simplest and most economical type of control system. Unfortunately, open-loop control systems lack accuracy and versatility and can be used in none but the simplest types of applications.

Consider, for example, control of the furnace for home heating. Let us assume that the furnace is equipped only with a timing device, which controls the on and off periods of the furnace. To regulate the temperature to the proper level, the human operator must estimate the amount of time required for the furnace to stay on and then set the timer accordingly. When the preset time is up, the furnace is turned off. However, it is quite likely that the house temperature is either above or below the desired value, owing to inaccuracy in the estimate. Without further deliberation, it is quite apparent that this type of control is inaccurate and unreliable. One reason for the inaccuracy lies in the fact that one may not know the exact characteristics of the furnace. The other factor is that one has no control over the outdoor temperature, which has a definite bearing on the indoor temperature. This also points to an important disadvantage of the performance of an open-loop control system, in that the system is not capable of adapting to variations in environmental conditions or to external disturbances. In the case of the furnace control, perhaps an experienced person can provide control for a certain desired temperature in the house; but if the doors or windows are opened or closed intermittently during the operating period, the final temperature inside the house will not be accurately regulated by the open-loop control.

An electric washing machine is another typical example of an open-loop system, because the amount of wash time is entirely determined by the judgment and estimation of the human operator. A true automatic electric washing machine should have the means of checking the cleanliness of the clothes continuously and turn itself off when the desired degree of cleanliness is reached.

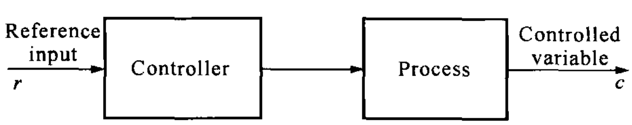

Fig. 1. 2 Block diagram of an open-loop control system

Although open-loop control systems are of limited use, they form the basic elements of the closed-loop control systems. In general, the elements of an open-loop control system are represented by the block diagram of Fig. 1. 2. An input signal or command r is applied to the controller, whose output acts as the actuating signal e; the actuating signal then actuates the controlled process and hopefully will drive the controlled variable c to the desired value.

Closed-loop Control Systems (Feedback Control Systems)

What is missing in the open-loop control system for more accurate and more adaptable control is a link of feedback from the output to the input of the system. In order to obtain more accurate control, the controlled signal $c(t)$ must be fed back and compared with the reference input, and an actuating signal proportional to the difference of the output and the input must be sent through the system to correct the error. A system with one or more feedback paths like that just described is called a closed-loop system. Human beings are probably the most complex and sophisticated feedback control system in existence. A human being may be considered to be a control system with many inputs and outputs, capable of carrying out highly complex operations.

To illustrate the human being as a feedback control system, let us consider that the objective is to reach for an object on a desk. As one is reaching for the object, the brain sends out a signal to the arm to perform the task. The eyes serve as a sensing device which feeds back continuously the position of the hand. The distance between the hand and the object is the error, which is eventually brought to zero as the hand reaches the object. This is a typical example of closed-loop control. However, if one is told to reach for the object and then is blindfolded, one can only reach toward the object by estimating its exact position. It is quite possible that the object may be missed by a wide margin. With the eyes blindfolded, the feedback path is broken, and the human is operating as an open-loop system. The example of the reaching of an object by a human being is described by the block diagram shown in Fig. 1. 3.

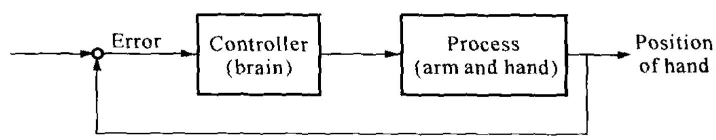

Fig. 1. 3 Block diagram of a human being as a closed-loop control system

As another illustrative example of a closed-loop control system, Fig. 1. 4

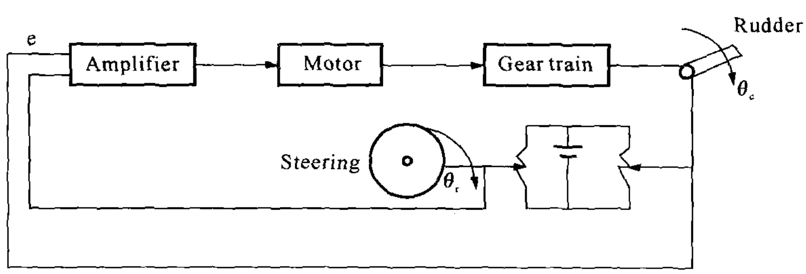

Fig. 1. 4 Rudder control system

shown the block diagram of the rudder control system of a ship. In this case the objective of control is the position of the rudder, and the reference input is applied through the steering wheel. The error between the relative positions of the steering wheel and the rudder is the signal, which actuates the controller and the motor. When the rudder is finally

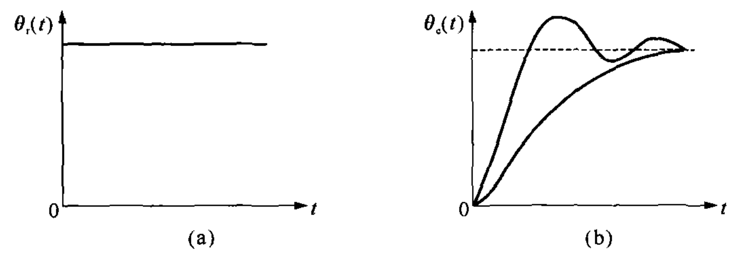

Fig. 1. 5 Action of rudder control system
(a) Step displacement input of rudder control system;
(b) Typical output responses

aligned with the desired reference direction, the output of the error sensor is zero. Let us assume that the steering wheel position is given as sudden rotation of R units, as shown by the time signal in Fig. 1. 5(a). The position of the rudder as a function of time, depending upon the characteristics of the system, say typically be one of the responses shown in Fig. 1. 5(b). Because all physical systems have electrical and mechanical inertia, the position of the rudder cannot respond instantaneously to a step input, but will, rather, move gradually toward the final desired position. Often, the response will oscillate about the final position before setting. It is apparent that for the rudder control it is desirable to have a nonoscillatory response.

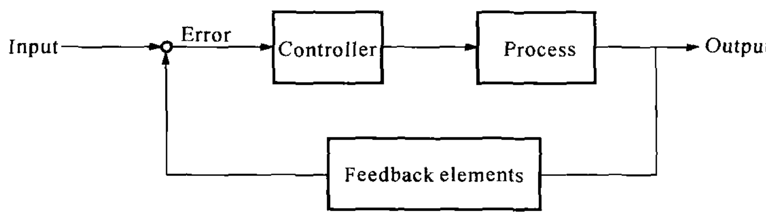

Fig. 1. 6 Basic elements of a feedback control system

The basic elements and the block diagram of a closed-loop control system are shown in Fig. 1. 6. In general, the configuration of a feedback control system may not be constrained to that of Fig. 1. 6. In complex systems there may be a multitude of feedback loops and element blocks.

New Words

1. assume	[ə'sjuːm]	*vt.*	承担,担任,接受
2. domestically	[də'mestikəli]	*ad.*	家庭地,民用地
3. advancement	[əd'vɑːnsmənt]	*n.*	前进,进步,提升
4. humidity	[hjuː'miditi]	*n.*	(空气的)湿度
5. transportation	[ˌtrænspɔː'teiʃən]	*n.*	运输,输送
6. inventory	['invəntri]	*n.*	详细目录,财产清册
7. environmental	[inˌvaiərən'məntl]	*a.*	周围的,环境的
8. hydrological	[hai'drɔlədʒikəl]	*a.*	水文的
9. prescribe	[pri'skraib]	*vt.*	开药方,指示所应遵循的行动方针
10. actuate	['æktjueit]	*vt.*	驱使,激励
11. variable	['vɛəriəbl]	*a.*	易变的,变化的
		n.	变量

12. multivariable	[ˌmʌlti'vɛəriəbl]	*n.*	多变量
13. feedback	['fiːdbæk]	*n.*	反馈，回授
14. adapt	[ə'dæpt]	*v.*	使适应，配合
15. respond	[ris'pɔnd]	*v.*	响应，感应
16. versatility	[ˌvəːsə'tiləti]	*n.*	多种功用，万能性，多才多艺
17. estimate	['estimeit]	*v.*	估计，估量
18. characteristic	[ˌkæriktə'ristik]	*a.*	特有的，有特色的
19. bearing	['bɛəriŋ]	*n.*	轴承，有支撑座架
20. external	[eks'təːnl]	*a.*	外部的，表面的
21. disturbance	[dis'təːbəns]	*n.*	扰动，干扰
22. intermittent	[ˌintə(ː)'mitənt]	*a.*	间歇(断)的，中断的
23. blindfold	['blaindfəld]	*a.*	盲的，蒙住眼睛的
24. margin	['maːdʒin]	*n.*	边(缘)余量，范围
25. rudder	['rʌdə]	*n.*	舵
26. align	[ə'lain]	*v.*	调整，匹配
27. inertia	[i'nəːʃjə]	*n.*	惯性，惯量
28. oscillate	['ɔsileit]	*v.*	振荡，振动，摆动
29. multitude	['mʌltitjuːd]	*n.*	许多，大批，多倍
30. sophistication	[səˌfisti'keiʃən]	*n.*	世故，老练，复杂
31. deliberation	[diˌlibə'reiʃən]	*n.*	慎重考虑，反复思考

Expressions and Terms

be aligned with	与……相一致
open-loop	开环
a multitude of	许多的，众多的

Notes

1. In order to obtain more accurate control, the controlled signal $c(t)$ must be fed back and compared with the reference input, and an actuating signal proportional to the difference of the output and the input must be sent through the system to correct the error.

proportional to the difference of the output and the input 作定语，修饰 actuating signal.

2. With the eyes blindfolded, the feedback path is broken, and the human is operating as an open-loop system.

眼睛被蒙住，反馈通路被切断，这个系统成为开环系统。

Unit Two Feedback Control

What is feedback

The concept of feedback plays an important role in control systems. We demonstrated in Unit one that feedback is a major requirement of a closed-loop control systems. Without feedback, control system would not be able to achieve the accuracy and reliability that are required in most practical applications. However, from a more rigorous standpoint, the definition and significance of feedback are much deeper and more difficult to demonstrate than the few examples given in Unit one. In reality, the reasons for using feedback carry far more meaning than the simple one of comparing the input with the output in order to reduce the error.

The class of control problems to be examined here is one of considerable engineering interest. We shall consider systems with several inputs, some known as controls because they may be manipulated and others called external disturbances, which are quite unpredictable. For example, in an industrial furnace we may consider the fuel flow, the ambient temperature, and the loading of material into the furnace to be inputs. Of these, the fuel flow is accessible and can readily be controlled, while the latter two are usually unpredictable disturbances.

In such situations, one aspect of the control problem is to determine how the controls should be manipulated so as to counteract the effects of the external disturbances on the state of the system. One possible approach to the solution of this problem is to use a continuous measurement of the disturbances, and from this and the known system equations to determine what the control inputs should be as functions of time to give appropriate control of the system state.

A different approach is to construct a feedback system, that is, rather than measure the disturbances directly and then compute their effects on the system from the model or system equations, we compare direct and continuous measurements of the accessible system states with signals representing their "desired values" to form an error signal, and use this signal to produce inputs to the system which will drive the error as close to zero as possible. Diagrams representing these two basic strategies of control are shown in Fig. 2. 1.

At first sight, the two approaches might appear to be essentially equivalent. Indeed, one might surmise that an open-loop control scheme is preferable since it is not necessary to wait until the disturbances have produced an undesirable change in the system state before corrective inputs can be computed and applied.

However, this advantage is more than outweighed by the disadvantages of open-loop control and the inherent advantages of feedback systems. First, in many cases the implementation of the open-loop control suggested above would require a very sophisticated computing device to determine the inputs required to counteract the predicted disturbance effects. Second, a feedback system turns out to be inherently far less sensitive to the accuracy with which a mathematical model of the system has been determined. Put another way, a properly designed feedback system will still operate satisfactorily even when the internal properties of the system change by significant amounts.

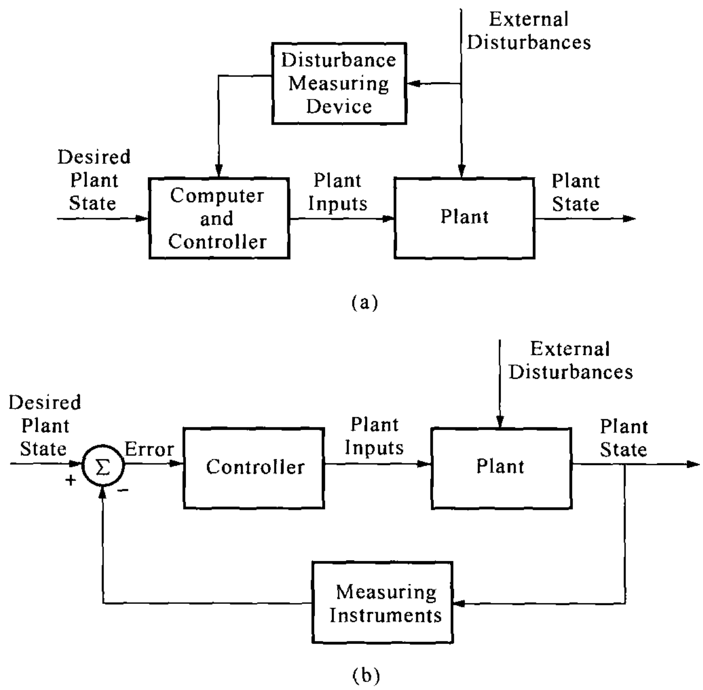

Fig. 2. 1 Schematic representation
(a)open-loop; (b)closed-loop

Another major advantage of the feedback approach is that by placing a "feedback loop" around a system which initially has quite unsatisfactory performance characteristics, one can in many cases construct a system with satisfactory behavior. Consider, for example, a rocket in vertical flight. This is essentially an inverted pendulum, balancing on the gas jet produced by the engine, and inherently unstable. It can be kept stable in vertical flight by appropriate changes in the direction of the exhaust jet, which may be achieved by rotating the engine on its gymbal mountings. The only satisfactory way of achieving these variations in jet direction is to use a feedback strategy in which continuous measurements of the angular motions of the rocket in two mutually perpendicular vertical planes cause a controller to make appropriate adjustments to the direction of the rocket engine. Stabilization of an inherently unstable system could not be achieved in practice by an open-loop control strategy.

In the simplest situation, one controls a single plant state variable, called the output, by means of adjustments to a single plant input. The problem is to design a feedback loop around the system which will ensure that the output changes in response to certain specified time functions or trajectories with an acceptable degree of accuracy. In either case, the transients which are inevitably excited should not be too "violent" or persist for too long.

In a typical situation, shown in Fig. 2. 2 we are given a system, or plant, with control input u, external disturbance d, and output y, all scalars. The problem is to design a feedback system around the plant consisting of (a) a device which produces a continuous measurement y_m of the output; (b) a comparator in which this signal is subtracted from a reference input (or set point, or desired output) y_r, representing the desired value of the output, to produce an error signal e; and (c) a controller which uses the error signal e to produce an appropriate input u to the plant. We shall call this configuration a single-loop feedback system, a term which is meant to convey the essential feature that just one of the plant states (the output y) is to be controlled using only one input. The objective of the feedback system is to make the output y follow its desired value y_r as closely as possible even in the presence of nonzero disturbances $d(t)$. The ability of a system to do so under steady-state conditions is known as static accuracy.

Frequently y_r is a constant, in which case we call the feedback system a regulator system. An example is the speed control system of a turbine-generator set in a power station, whose main purpose is to maintain the generator speed as nearly constant as possible. Sometimes y_r is a prescribed nonconstant function of time, such as a ramp function. An example of this would be the control system for a radar antenna whose axis is to be kept aligned with the line of sight to an aircraft flying past with constant angular velocity. In this case, we refer to the system as a tracking system.

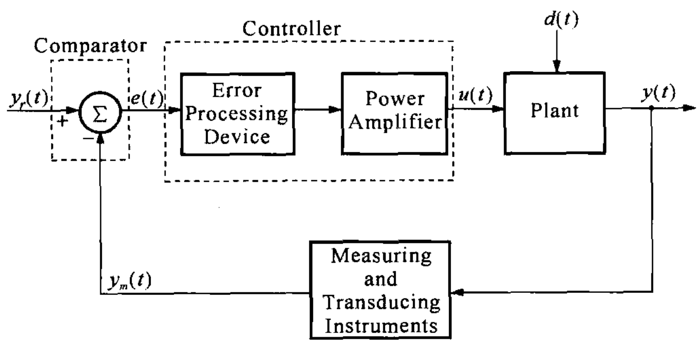

Fig. 2. 2 Structure of single-loop feedback system

Single-loop feedback systems with the structure of Fig. 2. 2 are often called servomechanisms because the controller usually includes a device giving considerable power amplification. For instance, in the control system of a hydroelectric turbine-generator set, the signals representing measured speed and desired speed might be voltages at a power level of milliwatts, while several hundred horsepower might be required to operate the main turbine valve regulating the water flow. This example also illustrates an important engineering constraint in the design of feedback control systems. In many applications, the plant and the activating device immediately preceding it operate at comparatively high power level, and their dynamic properties, if unsatisfactory for some reason, can be changed only at the expense of changing large, powerful, and hence costly components. Therefore the design of a feedback system is preferably done in the low-power components of the feedback system, i. e. , in the measuring elements and the controller.

The reduction of system error is merely one of the many effects that feedback may bring upon a system. We shall now show that feedback also has effects on such system performance characteristics as stability, bandwidth, overall gain, impedance, and sensitivity.

To understand the effects of feedback on a control system, it is essential that we examine this phenomenon with a board mind. When feedback is deliberately introduced for the purpose of control, its existence is easily identified. However, there are numerous situations wherein a physical system that we normally recognize as an inherently nonfeedback system, may turn out to have feedback when it is observed in a certain manner. In general, we can state that whenever a closed sequence of cause-and-effect relation exists among the variables of a system, feedback is said to exist. This viewpoint will inevitably admit feedback in a large number of systems that ordinarily would be identified as nonfeedback systems. However, with the availability of the feedback and control system theory, this general definition of feedback enables numerous systems, with or without physical feedback, to be studied in a systematic way once the existence of feedback the abovementioned sense is established.

We shall now investigate the effects of feedback on the various aspects of system performance. Without the necessary background and mathematical foundation of linear system theory, at this point we can only rely on simple static system notation for our discussion. Let us consider the simple feedback system configuration shown in Fig. 2. 3, where r is the input signal, c the output signal, e the error, and b the feedback signal. The parameters G and H may be considered as constant gains. By simple algebraic manipulations it is simple to show that the input-output relation of the system is

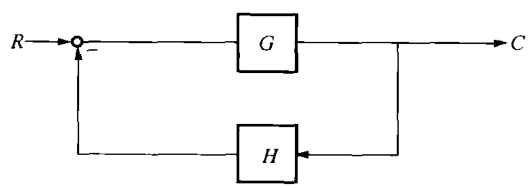

Fig. 2. 3 Feedback system

$$M=\frac{C}{R}=\frac{G}{1+GH} \tag{2 - 1}$$

Using this basic relationship of the feedback system structure, we can uncover some of the significant effects of feedback.

What are its effects

Effect of Feedback on Overall Gain

As seen from Eq. (2 - 1), feedback affects the gain G of a nonfeedback system by a factor of $1+GH$. The reference of the feedback in the system of Fig. 2. 3 is negative, since a minus sign is assigned to the feedback signal. The quantity GH may itself include a minus sign, so the general effect of feedback is that it may increase or decrease the gain. In a practical control system, G and H are functions of frequency, so the magnitude of $1+GH$ may be greater than 1 in one frequency range but less than 1 in another. Therefore, feedback could increase the gain of the system in one frequency range but decrease it in another.

Effect of Feedback on Stability

Stability is a notion that describes whether the system will be able to follow the input command. In a nonrigorous manner, a system is said to be unstable if its output is out of control or increases without bound.

To investigate the effect of feedback on stability, we can again refer to the expression in Eq. (2 - 1). If $GH=-1$, the output of the system is infinite for any finite input. Therefore, we may state that feedback can cause a system that is originally stable to become unstable. Certainly, feedback is a two-edged sword; when it is improperly used, it can be harmful. It should be pointed out however, that we are only dealing with the static case here, and, in general $GH=-1$ is not the only condition for instability.

It can be demonstrated that one of the advantages of incorporating feedback is that it can stabilize an unstable system. Let us assume that the feedback system in Fig. 2. 3 is unstable because $GH=-1$. If we introduce another feedback loop through a negative feedback of F, as shown in Fig. 2. 4, the input-output relation of the overall system is

$$\frac{C}{R}=\frac{G}{1+GH+GF} \tag{2 - 2}$$

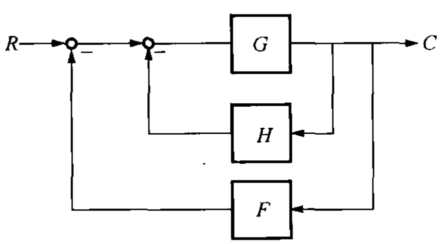

Fig. 2. 4 Feedback system with two feedback loops

It is apparent that although the properties of G and H are such that the inner-loop feedback system is unstable, because $GH=-1$, the overall system can be stable by properly selecting the outer-loop feedback gain F.

Effect of Feedback on Sensitivity

Sensitivity considerations often play an important role in the design of control systems. Since all physical elements have properties that change with environment and age, we cannot always consider the parameters of a control system to be completely stationary over the entire operating life of the system. For instance, the winding resistance of an electric motor change as the temperature of the motor rises during operation. In general, a good control system should be very insensitive to these parameter variations while still able to follow the command responsively. We shall investigate what effect feedback has on the sensitivity to parameter variations.

Referring to the system in Fig. 2. 3, we consider G as a parameter that may vary. The sensitivity of the gain of the overall system M to the variation in G is defined as

$$S_G^M=\frac{\partial M/M}{\partial G/G} \tag{2 - 3}$$

Where ∂M denotes the incremental change in M due to the incremental change in G; $\partial M/M$ and $\partial G/G$ denote the percentage change in M and G, respectively.

The expression of the sensitivity function S_G^M can be derived using Eq. (2 - 1). We have

$$S_G^M = \frac{\partial M}{\partial G}\frac{\Delta G}{\Delta M} = \frac{1}{1+GH} \qquad (2-4)$$

This relation shows that the sensitivity function can be made arbitrarily small by increasing GH, provided that the system remains stable. It is apparent that in an open-loop system the gain of the system will respond in a one-to-one fashion to the variation in G.

In general, the sensitivity of the system gain of a feedback system to parameter variations depends on where the parameter is located. The reader may derive the sensitivity of the system in Fig. 2. 3, due to the variation of H.

Effect of Feedback on External Disturbance or Noise

All physical control systems are subject to some types of extraneous signals or noise during operation. Examples of these signals are thermal noise voltage in electronic amplifiers and brush or commutator noise in electric motors.

The effect of feedback on noise depends greatly on where the noise is introduced into the system; no general conclusions can be made. However, in many situations, feedback can reduce the effect of noise on system performance.

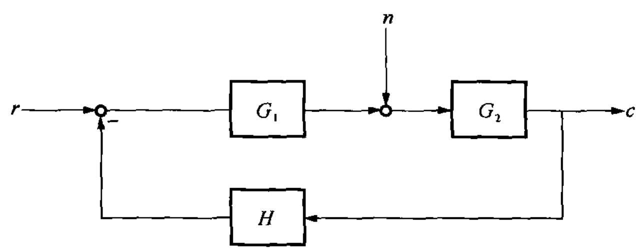

Fig. 2. 5 Feedback system with a noise signal

Let us refer to the system shown in Fig. 2. 5, in which r denotes the command signal and n is the noise signal. In the absence of feedback, $H=0$, the output c is

$$c = G_1G_2r + G_2n \qquad (2-5)$$

The signal-to-noise ratio of the output is defined as

$$\frac{\text{output due to signal}}{\text{output due to noise}} = \frac{G_1G_2r}{G_2n} = G_1\frac{r}{n} \qquad (2-6)$$

To increase the signal-to-noise ratio, evidently we should either increase the magnitude of G_1 or r relative to n. Varying the magnitude of G_2 would have no effect whatsoever on the ratio.

With the presence of feedback, the system output due to r and n acting. simultaneously is

$$c = \frac{G_1G_2}{1+G_1G_2H}r + \frac{G_2}{1+G_1G_2H}n \qquad (2-7)$$

Simply comparing Eq. (2 - 7) with Eq. (2 - 5) shows that the noise component in the output of Eq. (2 - 7) is reduced by the factor $1+G_1G_2H$, but the signal component is also reduced by the same amount. The signal-to-noise ratio is

$$\frac{\text{output due to signal}}{\text{output due to noise}} = \frac{G_1G_2r/(1+G_1G_2H)}{G_2n/(1+G_1G_2H)} = G_1\frac{r}{n} \qquad (2-8)$$

and is the same as that without feedback. In this case feedback is shown to have no direct