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TABLE OF CONTENTS

T-2262

ROCKET POWDER

by Tso Yang

Any kind of engine has to burn some suitable fuel to work. A steam engine burns coal, an internal combustion engine burns gasoline, a jet engine requires airplane gasoline or kerosene, to name a few. A solid fuel rocket engine burns rocket fuel suitable for the rocket.

Chemical rocket fuels can be divided into the solid type and the liquid type according to their physical state. Thus, rocket engines are categorized as solid rocket engines, liquid rocket engines and solid-liquid hybrid engines. Solid rocket fuel is customarily known as rocket powder since it evolved historically from gunpowder. Because powder has always been used in launching or propelling some kind of bullet or flying object, it is also known as ballistic or the propellant. In practice, all the different names are synonymous.

Powder, Common Fuel and Explosives

People unfamiliar with the subject often confuse powder with common fuel and explosives. It is well known that common fuel (such as coal, gasoline, etc.) can only burn if oxygen is supplied externally. Therefore, engines making use of such common fuel can work only in the atmosphere of the earth. On the other hand, the burning of powder requires no external oxygen since the powder itself contains oxygen. For example, the oldest and most ubiquitous kind of powder, black powder, consists of saltpeter, charcoal and sulfur, with saltpeter (potassium nitrate) serving as the oxygen supplier. Upon heating, the nitrate decomposes and releases the extra oxygen in its molecules which facilitates the burning of charcoal and sulfur. The oxygen supplier in the powder is called the oxidizer and the combustible material is known as the incendiary agent. With both oxidizing and combustible agents present in the powder, its combustion does not rely on the oxygen in the surrounding air. This is the basic difference between powder and common fuel, and is the precise reason that rockets carrying its own oxygen and combustible can fly in a vacuum and carry out flight missions to outerspace -- something impossible to achieve by airplanes using ordinary fuel. (See Fig. 1)

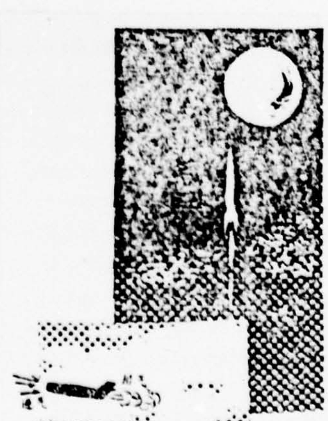


Fig. 1

If powders are dangerous flammable material, how are they different from explosives? Although powder and explosives share some similarities, they also have differences. The basic means of application of the powder is combustion, i.e., decomposition into combustion products at high temperatures and within some duration of time. The propagation speed of combustion is approximately 2 $\approx$ 250 mm/sec. Dynamite is normally used in explosions to produce a shock wave strong enough to cause massive damage to the surroundings. The explosion is an instant decomposition into a vast amount of high temperature gas with a propagation speed of 700 $\sim$ 8500 m/sec. However, under certain circumstances, powder can also react explosively and the explosives may burn quietly depending upon the conditons of stimulation energy from the external environment. The distinction lies in the fact that the burning of powder can be stable and controllable while the burning of explosive cannot be. Hence, we can view powder as one kind of explosive usable in explosion operations whereas dynamite cannot necessarily be used as a propellant.

The Black Powder

Black powder, magnetic needle, printing and paper making are the four great technological inventions of the working people of ancient China. We, the Chinese as a nation, are proud of the four inventions highly significant in the economic and cultural development of the world. The Chinese people discovered the calcination property of saltpeter before the time of Christ. In A.D. 682, Sun Saŭmiso of the T'ang Dynasty described black powder or a similar substance in his book "Tan Ching" (a work on medicine) and early models of military rockets using black powder appeared in the years of Sung and Chin (11 - 12 century A.D.). Figure 2 shows a rocket weapon which appeared during the Ming Dynasty (1368 $\sim$ 1644 A.D.). The knowledge on saltpeter and powder was carried from China to India, Arabia, Greece and eventually to Europe. Until the 19th century, black powder was the only gunpowder at the time.

The composition of today's black powder is 75% saltpeter, 15% charcoal, and 10% sulfur. It also assumes the name of smoking powder due to the

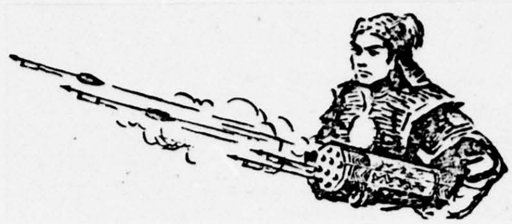


Fig. 2

large amount of solid particles in the form of a dense smoke as the combustion product. Since the energy content of black powder is relatively low and it is also difficult to form large charges, black powder is no longer used as the charge of a rocket but as the ignition for the main charge instead.

Black powder is easy to manufacture by crude methods which are popular among the civilians of our nation. For instance, the anti-hail rocket currently being popularized in the countryside can use black powder as the main charge. It can also be used as an explosive in home made land mine or in explosion operations. In times of war, especially during a people's antiaggression war which may take place on our land, black powder still has its place.

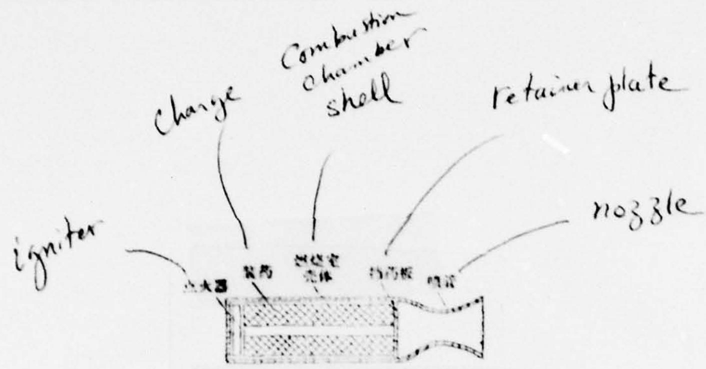
Dual-Base Powder

The emergence of nitrocellulose powder in the late nineteenth century marked a significant stride in the history of powder development. Nitro-cotton (also known as pyroxylin) is the product of nitrated cotton cellulose. It has a similar appearance to ordinary cotton but slightly stiffer. Nitro-cotton is not water soluble but can be dissolved in some organic solvents. It is difficult to form "sticks" of a usable shape and density with nitro-cotton alone, however, organic solvents can be added to increase its plasticity and to form sticks. Single-base powder with a nitro-cotton content of 90% or more is produced by dissolving nitro-cotton in a mixture of alcohol and ether to form sticks, and then bake out the solvent. Although the single base powder contains more energy than black powder, its energy content is still considered to be low from the rocket technology standpoint. Besides, since organic solvents need to be baked out, granule or pillets are opted instead of the more difficult stick shape. Single base powders are generally used as gunpowder, rarely as a rocket fuel.

The solvent used in producing dual-base powder is nitroglycerine -- nitrated glycerol -- a high explosive with large energy content. When the nitro-cotton and the nitroglycerine are mixed at an appropriate ratio, the nitro-cotton will gradually be dissolved into nitroglycerine under the action of heat and pressure. It can then be molded into pieces of specific geometry and uniform density. Since the two main ingredients, nitro-cotton and nitroglycerine, account for more than 80% of this kind of powder (the rest, 20%, consists of various additives of special purposes), it is called the dual-base powder or the ballistic powder.

Dual-base powder has a higher energy content than that of black powder and single-base powder. Large sticks with good combustion characteristics (almost smokeless) can be made out of dual-base powder. It is widely used, not only in fire arms and guns of medium to large caliber, but also has a place in rocket weapons.

Dual-base powder is ordinarily used in the free-loading style, as seen in Figure 3. Sticks of the required geometry and dimension are fabricated using dual-base powder. They are then loaded into the combustion chamber of the rocket engine and fixed in place via the retainer



图三 自由装填式装药火箭发动机

Fig. 3 Free loading style powder rocket engine

plate. The maximum diameter of the powder sticks is approximately 500 mm according to the capacity of currently available pressing and molding facilities. Such fabrication techniques have already matured to a large production capacity in turning dual-base powders into propellants for medium or small size rocket engines. The first generation air-to-air missile of the U.S. "Side Winder 1-A" and surface-to-air missile "Terrier" both used dual-base powder. The auxiliary booster of SAM 2, a Russian antiaircraft missile, also uses the dual-base fuel.

Compound Powder

Compound or complex powder is a mechanical mixture of the components it contains. Black powder is the earliest compound powder. The basic ingredients of a modern day compound powder are inorganic salt oxidants (such as ammonium nitrate, potassium perchlorate, ammonium perchlorate, etc.), plastic and rubber-like high polymer cohesive materials. In addition, metal powders (such as aluminum) are used as high energy combustants and small amounts of other additives are generally used.

Among the compound powders commonly used, the oxidant is generally ammonium perchlorate and the cohesive materials include polychloroethylene, polysulfur rubber, polyaminoplast, polybutadiene rubber, and dual-base cohesive agents. The last type has nitro-cotton and nitroglycerine as the cohesion agent and is therefore known as the compound modified-dual-base powder.

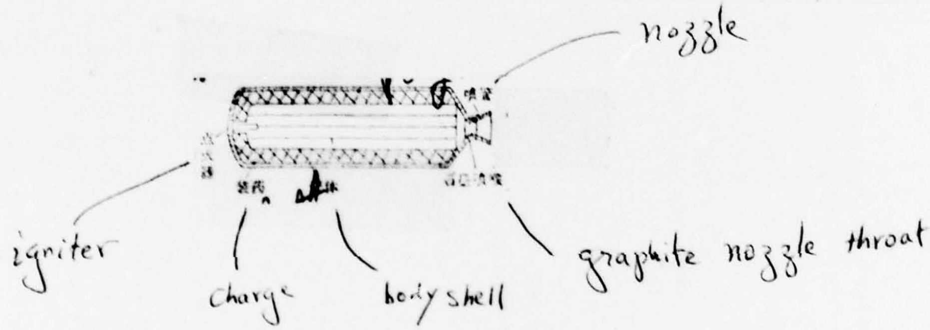


Fig. 4 Shell-cohesion type charge for rocket engine

The technique of making compound powder normally follows the "pouring" method where various ingredients are mixed to form a pourable batter. The batter is poured directly into the combustion chamber of the engine, as shown in Fig. 4. After a few days of "solidification," the powder will become an elastic charge attached to the inner surface of the engine chamber. This type of charge is known as the shell cohesion charge and this technique can be used in producing charges of several meters diameter and several hundred tons in giant rocket engines, as can be seen in Fig. 5.

The compound powder outperforms the dual-base powder in the following categories:

a) High energy content. In rocket technology, the physical quantity used in measuring the energy content of the powder is the specific impulse,

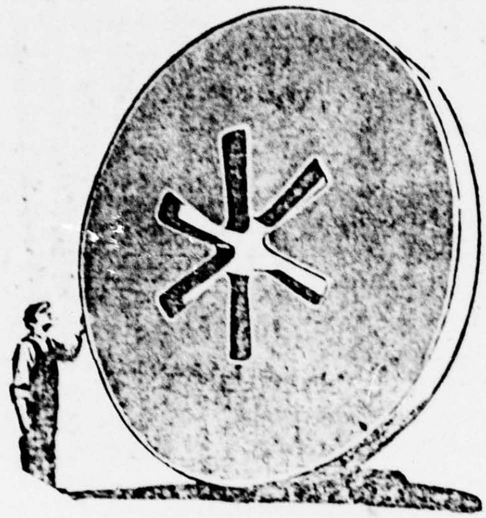


Fig. 5 Cross sectional view of giant rocket engine

that is, the thrust force produced by 1 Kg of powder in 1 sec. The unit of specific impulse is Kg · sec/ Kg, generally known as "sec." The table in Fig. 6 is a comparison of the specific impulse of several kinds of powders. Notice that compound powder and modified dual-base powder are leaders in this category.

b) High specific gravity. The specific gravity of the compound powder is approximately between 1.67 to 1.8 gm/cm^3, as compared to that of the dual-base powder's 1.57 to 1.66 gm/cm^3. Powders of high specific gravity have the obvious advantage of more loaded powder per volume, thereby reducing the volume of the rocket engine or a longer range for the same engine volume.

c) Wide temperature range of operation. Generally speaking, the operating temperature range of a high quality compound powder is between +60° C and -60° C. The range for dual-base powder is narrower, approximately

$+15^{o}$ C to -40^{o} C, and the action at low temperatures cannot be ensured.

d) Wide range of combustion speed. One of the important characteristic parameters of rocket powder is its combustion speed. The combustion speed is not directly related to the quality of the powder. Various kinds of rocket engines have different requirements on the combustion speed: some demand a high burning speed and others may require a slow burning speed. A powder with a wide range of burning speeds is desirable. The speed ranges of dual-base powders are relatively narrow; in particular, very few dual-base powders have combustion speed less than 4 mm/sec. On the other hand, the wide rnage of combustion speeds of a compound powder covers 1 to 50 mm/sec.

e) Economic considerations. The major components of a compound powder can all be chemically synthesized, produced on a large scale from an abundant supply. The ingredients of a dual-base powder, glycerine and cotton, must rely on agricultural by-products and therefore are of limited supply. The current going price of the compound powder in foreign nations is only about 1/5 of the dual-base powder price.

f) Technical considerations. The manufacturing process for compound powders in relatively straightforward and requires few specialized facilities. Since the pouring method is employed, there is essentially no limit on the size of the powder rods to be made.

Naturally, the compound powder has its shortcomings; for example, its mechanical strength is low and the smoke after combustion can be an irritating problem in certain situations. Since the plastic and rubber-like material have their usual aging problems, the storage time of compound powders is only about five to ten years as compared to the thirty years of the dual-base powder.

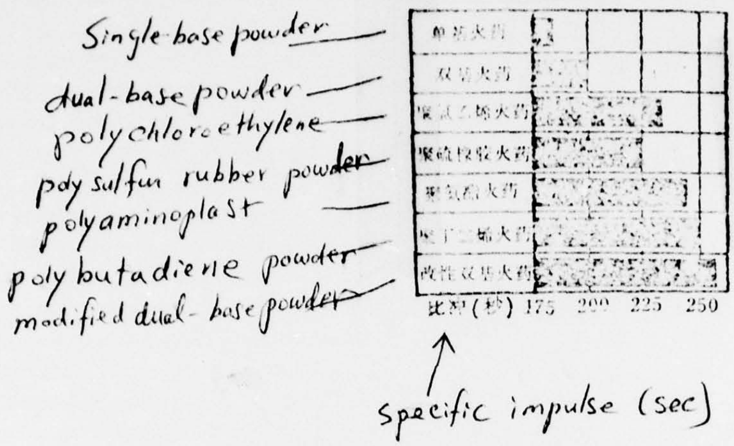


Fig. 6 Specific impulse of various kinds of powders

Among the various kinds of rocket powders, the compound charge is meritorious in many aspects. It is also rapidly developing and has a great potential even though it came into existence only after World War II. It now plays an important role in rocketry and powers anything from small or medium rocket weapons to giant intercontinental guided missiles and rockets used in space flights. For example, the American Imperialists' three-stage solid fuel ICBM Minuteman III uses a polybutadiene compound charge in its first and second stages and compound modified-dual-base powder in its third stage. The submarine launched intermediate range guided missile Polaris A3 takes polyaminoplast compound powder in its first stage and modified-dual-base in the second stage.

Along with the continuous development of rocket technology, the demands put on rocket fuel are becoming more and more challenging. The most widely used rocket charges are the dual-base powder and the ammonium percholorate compound powder introduced in this article. With specific impulse values of 200 - 250 sec, the energy contents of these powders can only be considered medium. The specific impulse of the widely used liquid fuel can be as high as 280 - 300 sec. Many nations are making great efforts in developing new high-energy rocket fuels based on powerful oxidants such as hydrazine perchlorates and nitrophenol perchlorate, and high energy combustants such as lithium metal, beryllium metal, and metal hydrides. Such high energy rocket fuel may have a specific impulse of 300 sec. The development of high energy rocket fuel is still in the research stage since much has to be done in solving problems on their chemical incompatibility, instability, poisonous properties and economic considerations.

Figures by Shaw Hsien

RADIO TELEMETRY ON ARTIFICIAL SATELLITES

Wu Ling-Yao

The preceding issue of this journal has introduced the first part of the article; presented below as a continuation is the second part describing various methods and the underlying principles of the radio telemetry used on artificial satellites.

During the motion of an artificial satellite along its course, there are numerous engineering parameters and scanning (searching) parameters which the ground needs to know. On the satellite, sensors, telemeters, and remote sensors are so abundantly installed that the telemetering parameters amount to hundreds. Whether these are the engineering parameters or scanning (searching) ones, people mostly hope to know the regularities of their continuous variations with time. This demands the telemetry system to be capable of transmitting simultaneously and continuously up to a hundred parameters. If each telemetering signal is to modulate one carrier wave then the satellite has to be equipped with a hundred transmitters. This is, no doubt, not economic nor practical. However, if many telemetering signals emitted from the various sensors were allowed to simultaneously modulate one carrier wave, then all these signals would be confused. The situation would be similar to simultaneously loading several different kinds of rice seeds onto one truck, causing them to be mixed up. When these different kinds of rice seeds reach the receiving station, there is no way to separate them. One may ask: Is there, after all, any way to allow the numerous telemetering signals to simultaneously transmit without errors so that they can be conveniently discriminated on their arrival on the ground? "There is no difficult thing on earth so long as there is a will to work." Through practice people have eventually found several methods of telemetering, among which the commonly used ones are the following two kinds; frequency discrimination multichannel and the other time discrimination multichannel.

Frequency discrimination multichannel telemetering

Let us consider as an example the transportation of the rice seeds by a truck. Suppose that there are No. 1, No. 2, No. 3, and No. 4, four kinds of rice seeds to be transported. Before being loaded onto the truck the four kinds of rice seeds are separately put into four kinds of hemp cloth bags which can hold weights of 100, 120, 130, and 140 catties* respectively. Thus at the receiving station one only has to "weigh" all the hemp cloth bags first, then he separates the bags which hold the different rice seeds according to their weights and finally opens them to get the rice seeds. To apply a similar method, suppose that it is required to simultaneously transmit four telemetering signals. We first use these four signals to modulate, respectively, 1000 Hz, 2000 Hz, 3000 Hz, and 4000 Hz oscillations of four different frequencies. The four oscillations under modulation are called auxiliary carrier waves. These four modulated auxiliary carrier waves are then superposed and used to modulate a transmitter where a carrier wave carrying them is transmitted. After being received by the ground station the carrier wave is sent to band-pass filters for filtering, which allow only those frequencies lying within the assigned limits of the bands to pass. As indicated in Figure 7, the No. 1 band-pass filter allows only waves of frequencies around 1000 Hz to pass, the No. 2 band-pass filter allows only waves of frequencies around 2000 Hz to pass, and so on. This way the four band-pass filters discriminate the four auxiliary carrier waves of 1000 Hz, 2000 Hz, 3000 Hz, and 4000 Hz. These waves are then separately subjected to demodulation, extracting the telemetering signals carried by them. Due to the fact that this way of multichannel telemetering uses the feature of the different frequencies in the auxiliary carrier waves in discriminating channels/telemetering, it is therefore called multichannel telemetering by frequency discrimination, or briefly frequency discrimination multichannel telemetering.

(Fig.7 to appear on next page)

*Catty, a Chinese unit of weight.

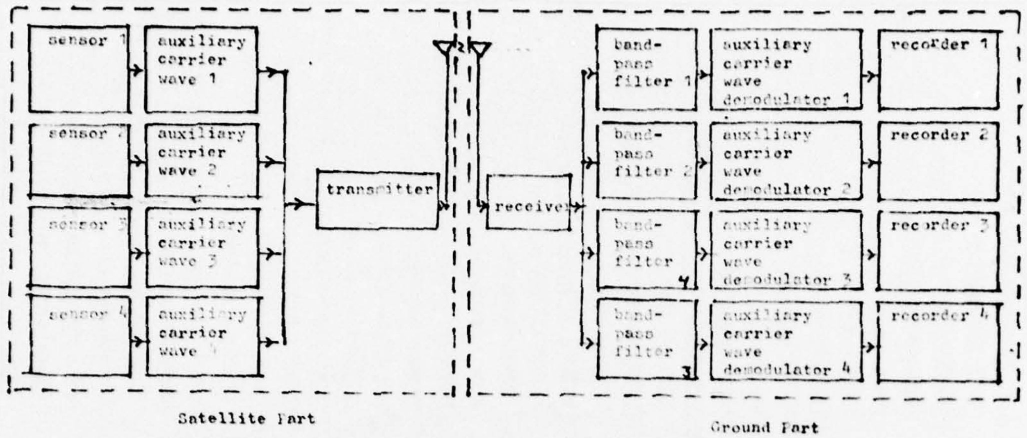


Figure 7. Sketch Diagram of Frequency Discrimination Multi-channel Telemetering.

In the frequency discrimination multichannel telemetering system, the frequency separation intervals among the auxiliary carrier waves must be sufficiently large in order to prevent mutual interference. The number of channels in the system, i.e. the number of the auxiliary carrier waves, must not be too large. This is because of the fact that, the more auxiliary carrier waves there are, the smaller the frequency separations among them will be and the more easily mutual interference will be produced. At present the channel number in a typical frequency discrimination multichannel telemetering system does not exceed 15.

In order to realize the frequency discrimination multichannel telemetering, it is necessary to increase the oscillators for the auxiliary carrier waves and their modulation processes. The modulation of these auxiliary waves by telemetering signals may be any one of the three kinds: amplitude modulation, frequency modulation, and phase modulation. The modulation of the carrier wave also may be any one of the above-mentioned three kinds. Combinations of both modulations constitute the amplitude modulation-amplitude modulation (the former refers to an auxiliary carrier wave while the latter to a carrier wave), the amplitude modulation-frequency modulation, the frequency modulation-frequency modulation, and frequency modulation-phase modulation, etc., altogether nine types of " twice modulation". Since the frequency modulation has good quality against interference and a broad frequency band as its advantages, nowadays the most used modulation is the frequency modulation-frequency modulation. In recent years, following the development of the phase-lock technique the ground stations have employed the method of phase-lock reception to receive phase modulated waves, which can appreciably raise the accuracy of the telemetering signals. Therefore the phase modulation of carrier waves also has gradually become popular.

Time discrimination multichannel telemetering

Concerning the time discrimination multichannel telemetering, its principle of operation is that the transmitter transmits by turns the several telemetering signals at different times. We still use the example of transporting the four kinds of rice seeds for illustration. Suppose that a number of trucks move along one after another. Let the first truck carry the No. 1 rice seeds, and the second truck the No. 2 rice seeds, etc.....

Coming to the fifth truck, it also carries the No. 1 rice seeds, and the sixth truck also carries the No. 2 rice seeds, etc..... This cyclic pattern repeats itself. The receiving station would identify the different numbers of the rice seeds by the order of arrival of the trucks. In the process of transmitting telemetering parameters, the earlier and later times correspond to the order of the trucks. Let the transmitter transmit in the first time-interval the telemetering signal from the No. 1 sensor, and in the second time-interval the signal from the No. 2 sensor, etc.,.... In the fifth time-interval, it would again transmit the signal from the No. 1 sensor.......and thus go on transmitting cyclically.

The cyclic transmission of telemetering signals is achieved through the function of a channel-switch which connects by turns the four sensors to the transmitter. Thus the modulated telemetering signals on the carrier wave belong , respectively, to the four telemetering signals at different time-intervals. (Figure 8). At the ground receiving station there is a corresponding channel-switch which discriminates the four signals according to the time order. The ground channel-switch must be strictly synchronized with that on the satellite (Figure 9), or else an error would occur on receiving such as: the telemetering signal from the No. 1 sensor being taken as that from the No. 2 sensor, etc.--- a situation similar to that described as "Mr. Lee puts on Mr. Chang's hat."

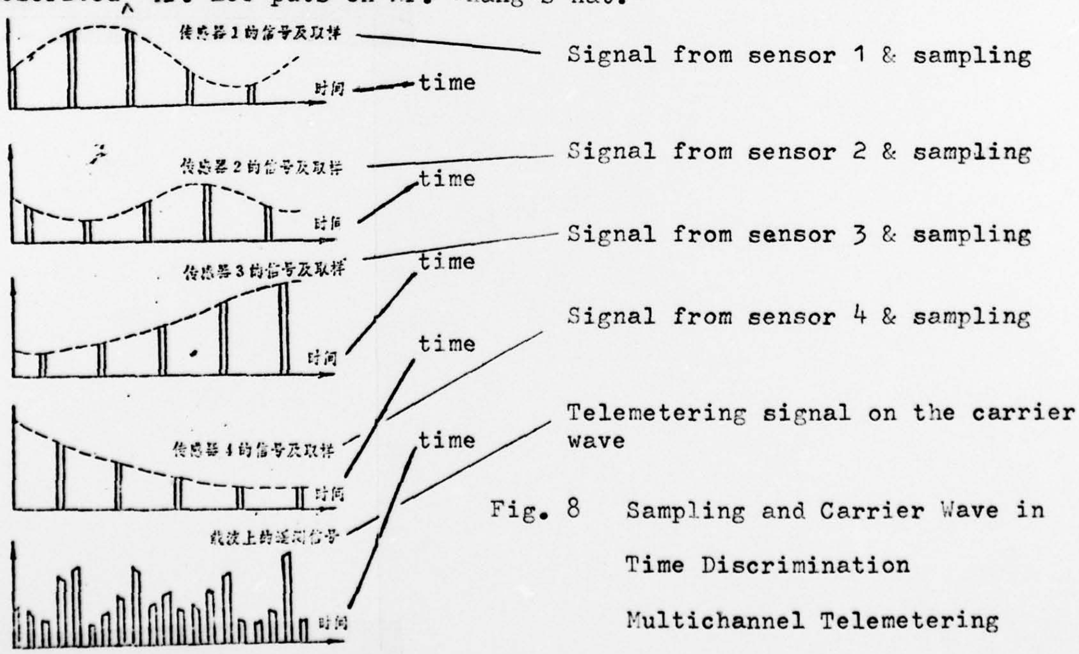
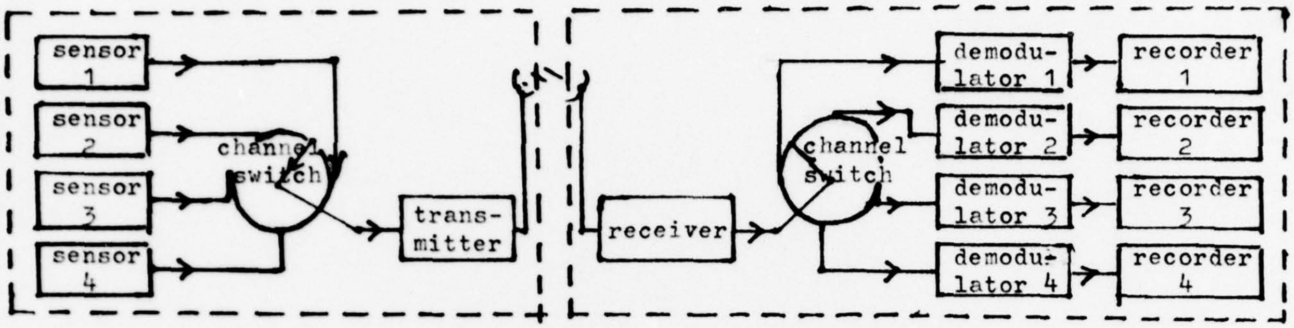


Fig. 8 Sampling and Carrier Wave in Time Discrimination Multichannel Telemetering



Satellite Part

Ground Part

Fig. 9 Diagram Of Time Discrimination Multichannel Telemetering

sampling order
sampling value
quantified value
quantification error
binary code
pulse group

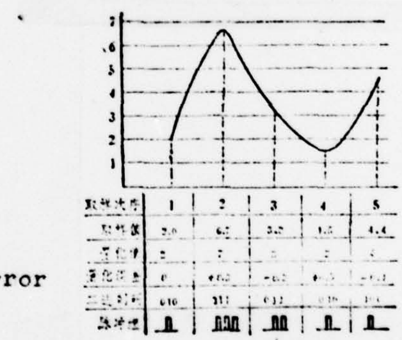
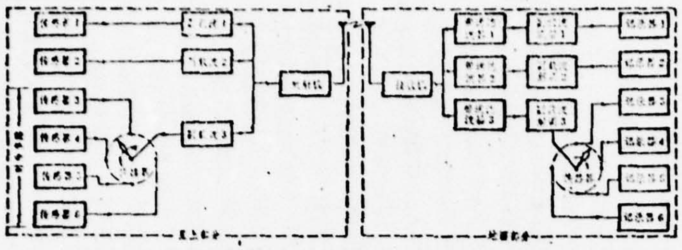


Fig. 11 Transformation Process In Pulse Coded Modulation



sensor 1
auxiliary carrier wave 1
sensor 2
auxiliary carrier wave 2
sensor 3
sensor 4
sensor 5
sensor 6
channel switch
auxiliary carrier wave 3
transmitter
receiver
band-pass filter 1
auxiliary carrier wave demodulator 1
band-pass filter 2
auxiliary carrier wave demodulator 2
band-pass filter 3
auxiliary carrier wave demodulator 3
channel switch
recorder 1
recorder 2
recorder 3
recorder 4
recorder 5
recorder 6
time discrimination multi-channel
Satellite part
Ground part

Figure 10. Diagram indicating combined use of frequency discrimination and time discrimination.

As seen from the Fig. 8, the time discrimination multichannel telemetering actually decomposes the continuously varying signal into many disjoined signals for transmission. When the channel-switch connects a certain sensor once, one value is extracted from the telemetering signal transmitted by that sensor. This process is called sampling. The signal received by the ground station is just one disjoined signal. Can such disjoined signals represent the original continuously varying signal? Theoretically, it can be shown that these received disjoined signals can perfectly represent the original, continuous signal provided the number of samplings per sec of the telemetering signal is greater than twice the maximum frequency of that signal. In practice, the channel exchange from one sensor to another as made by an electronic channel-switch is instantaneous, and the duration of connecting with each sensor is also very short. Therefore, despite the large number of sensors, the time separation interval between the preceding and subsequent samplings of each telemetering signal is still very small. Moreover, the majority of the measured engineering parameters and scanning parameters vary very slowly and their maximum frequencies are very low. It is very feasible to make the number of samplings per sec greater than twice the maximum frequency of a signal. Of course, for certain rapidly varying telemetering parameters their transmission requires the use of the frequency discrimination multichannel telemetering.

In practical systems, usually there involve both the frequency discrimination multichannel and the time discrimination multichannel, which are used in combination to supplement each other (Figure 10). The frequency discrimination multichannels transmit the rapidly varying parameters while the time discrimination multichannels transmit the slowly varying parameters.

Pulse coded modulation

Since the telemetry system is a device which performs long-distance measurements and transmits numerical data, so one important index indicating the goodness of its quality is "distortion-free" feature of the telemetering parameters after remote transmissions so that the ground demodulated parameters with small errors would agree with the actual values as closely as possible. The main source of errors in the telemetry comes from the interference caused by the random electric waves in the transmission process.

Currently, in the telemetry system of an artificial satellite a method of modulation by pulse coding, briefly called pulse coded modulation, is widely employed. This is an advanced modulation scheme which fundamentally strengthens the capability of the telemetry system against interference, thereby increasing the precision of telemetering.

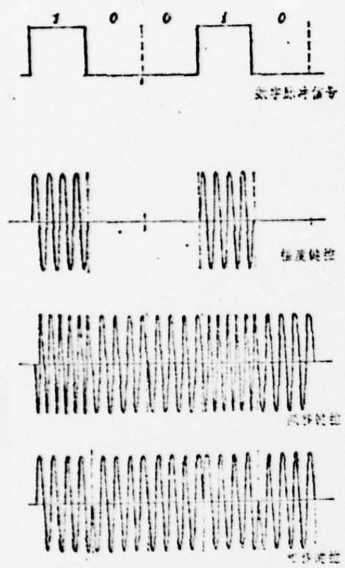
As mentioned before, the signal transmitted from a sensor is an electric voltage signal which is proportional to the magnitude of a parameter to be measured. Since variations of the electric voltage are used to simulate variations of the measured parameter so the signal is a kind of simulating signal. The modulations as described previously imply the use of such simulating signals to modulate the auxiliary carrier waves or the carrier wave so that their amplitudes (frequencies or phases) vary continuously according to the high or low electric voltages of the simulating signals. This kind of modulation is called simulation modulation. The pulse coded modulation is, however, a kind of number modulation, qualitatively different from the simulation modulation. Its characteristic is that the signal transmitted from a sensor must first be processed through "pulse coding". After "transforming" the simulating signal into a pulse signal represented by coding numbers, the presence or absence of the pulse is utilized to modulate an auxiliary carrier wave or the carrier wave. The "transformation" process consists of three steps: sampling, quantification, and coding (Figure 11).

The first step is to make samplings of the simulating signal of a telemetering parameter transmitted from a sensor, turning the continuous signal into a series of disjoined values taken at different time intervals. This process is identical with the samplings made in the time discrimination multichannel telemetering. For each simulating signal the number of samplings per sec should be greater than twice the possible maximum frequency of that signal.

The second step is quantification, which means conversion of the numerical values obtained from sampling into standard values, also called quantified values. The method of quantification consists in dividing the possibly obtained maximum value from a simulating signal into 2^n levels (layers) and assigning to the sampling values the standard values, each of which takes only one certain integer out of the 2^n integers associated with the 2^n levels. For instance (Fig. 11), n=3, 2^n=8, so divide the possible maximum value, 8, into 0, 1, 2, 3, 4, 5, 6, and 7, i.e. 8 levels. Any one value of the sampling is converted into one of the eight integral values from 0 to 7 inclusive by the method of neglecting decimals ≤ 0.4 and rounding off to a value of 1 for decimals ≥ 0.5. For example, in the Fig. 11 the value of the third sampling is 3.2, for which the standard value of 3 is obtained according to the above approximate method. The third step is coding. After being converted to an integral quantified value, a sampling value still remains a simulating quantity. The key step is to transform it into a binary code. The number of digits used in the binary number code is just the value of n chosen in the division into levels in quantification. Since n=3, so, there are 3 digits in the codes. These 3 digit codes can represent the 8 numbers from 0 to 7, as shown in the following table:

quantified value	0	1	2	3	4	5	6	7
binary code	000	001	010	011	100	101	110	111

After it has been transformed to a binary number code, a sampling value may be represented by a combination of the presence or absence of a pulse. The presence of a pulse signifies "1" while the absence of it indicates "0". As examples, 3 successive pulses represent 111 (or 7); no pulse for the head and tail digits with only one pulse for the middle digit refers to 010 (or 2). A group of pulses is used to modulate auxiliary carrier waves or carrier waves. Using the presence or absence of pulses to modulate is essentially equivalent to applying an off-and-on switch type of control to the auxiliary carrier waves or carrier waves. This kind of modulation is called the key control. For instance, in amplitude modulating an auxiliary carrier wave, when there is a pulse the auxiliary carrier wave appears and the amplitude has its normal value; but in the absence of a pulse the auxiliary carrier wave disappears and the amplitude is zero. This type is called amplitude-key-control. In the case of frequency modulation, when there is a pulse there results a steady shift in the frequency of the auxiliary carrier wave, but in the absence of a pulse the auxiliary carrier wave retains its center frequency. This type is called frequency-shift-key-control. Similarly, the process of using the presence or absence of a pulse in phase modulation is called the phase-shift-key-control. That is, in the presence of a pulse the phase of an auxiliary carrier wave is shifted by 180° while in the absence of a pulse the phase is normal (Fig. 12).



— Code-number pulse signal

— Amplitude-key-control

— Frequency-shift-key-control

Phase-shift-key-control

图十二 脉码调制的三种调制方法

Fig. 12:
Three kinds of modulation in pulse-coded modulation

The most advantageous feature in employing the pulse-coded modulation lies in the fact that it enables a telemetering signal to remain essentially unaffected by the interference of the random electric waves during transmission process. In its entire course of transmission beginning with the emission from a satellite and ending with the reception by a ground station, a carrier wave often has a varying amplitude due to the interference by the random electric waves, which produce an extra amplitude modulation. When the simulation modulation is used in the amplitude modulation, this extra amplitude modulation constitutes the error. However, when the pulse coded modulation is employed to perform the function of the amplitude-key-control for the carrier wave from the transmitter, the demodulation at the ground only requires the judgment of whether the carrier wave is present or not, the magnitude of its amplitude being irrelevant. Hence the extra modulated amplitude would not play too important a role. It may be seen from the Fig. 13 that due to the interference of the random electric waves which is experienced by the carrier wave in the transmission process, there results an extra variation in the carrier wave amplitude. The form of the pulse obtained through demodulation after its reception at the ground looks almost entirely different from the original one.

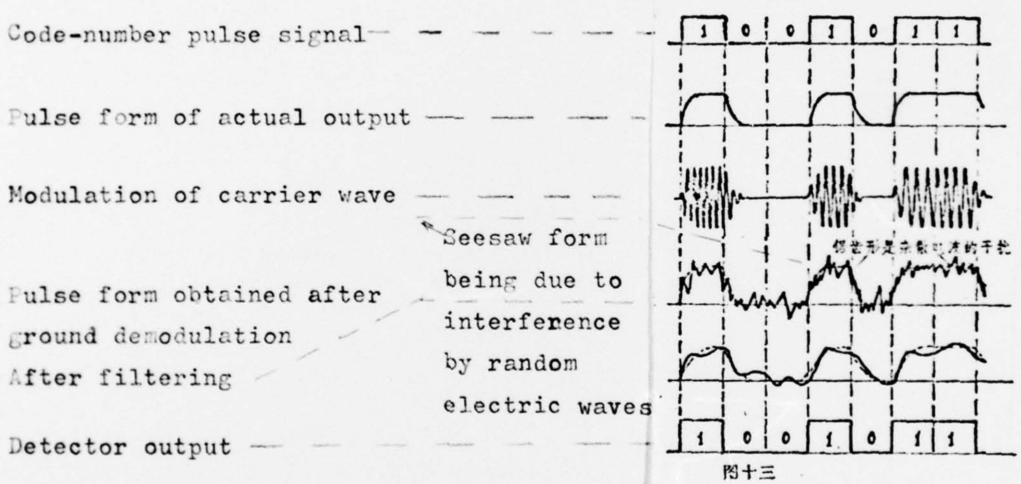


Fig. 13

However, in detection it is only necessary to identify the presence or absence of the carrier wave. When its amplitude is not smaller than a half of its normal value the whole pulse can be retrieved. When its amplitude does not reach a half of its normal value, the pulse is considered as absent. Therefore, the error of mixing up 0 and 1 would occur only if an extraordinary large interference should take place so that it reduces the carrier wave amplitude by more than a half, or it generates an extra amplitude larger than a half of the normal value in a time interval during which there is no pulse. However, the chance for such extra-ordinarily large interference to happen is very small. Similarly when modulation by frequency-shift-key-control or by phase-shift-key-control is employed, again demodulation at the ground only requires the judgment of whether there is or is not a frequency shift or a phase shift, independent of the magnitude of the shift. Hence, variations in magnitude of the shift caused by the interference also do not under the usual conditions, lead to errors. However, in the case of using simulation modulation in amplitude modulation or phase modulation, the magnitude of the frequency shift or the phase shift signifies the magnitude of a telemetering signal. Therefore, the additional frequency shift or phase shift produced by the interference will constitute an error in the telemetering signal. From this it may be seen that often its transformation through such pulse coding the ability of the telemetering signal against interference is greatly strenthened. In comparison with the simulation modulation, the pulse coded modulation is able to reduce appreciably the errors in the telemetry and to increase its accuracy. But the pulse coded modulation itself carrier along the "quantification errors", which come about as a result of the approximate method used in rounding off a decimal numeral into an integer. One method to decrease the quantification errors is to increase the number of levels so that the separations between two successive levels are reduced.

Most of the practical pulse coded modulation systems are of the twice modulation type: a code-number-pulsed telemetering signal modulates an auxiliary carrier wave, which in turn modulates a carrier wave.

The transformation of a simulating signal into a code number signal is accomplished with the aid of a simulation-number coding changer, i.e. an encoder. In the pulse coded modulation system, an encoder must be added between the sensors and the transmitter (Figure 14). Correspondingly, the ground receiving station must be eqipped with a device which transforms the number-coded signal back to the simulating signal.--a device called a number coding-simulation changer, or decoder. This device facilitates the retrieval of the simulating (signal) electric voltages from the binary number codes obtained after demodulation; these electric voltages will then be amplified and recorded or displayed.

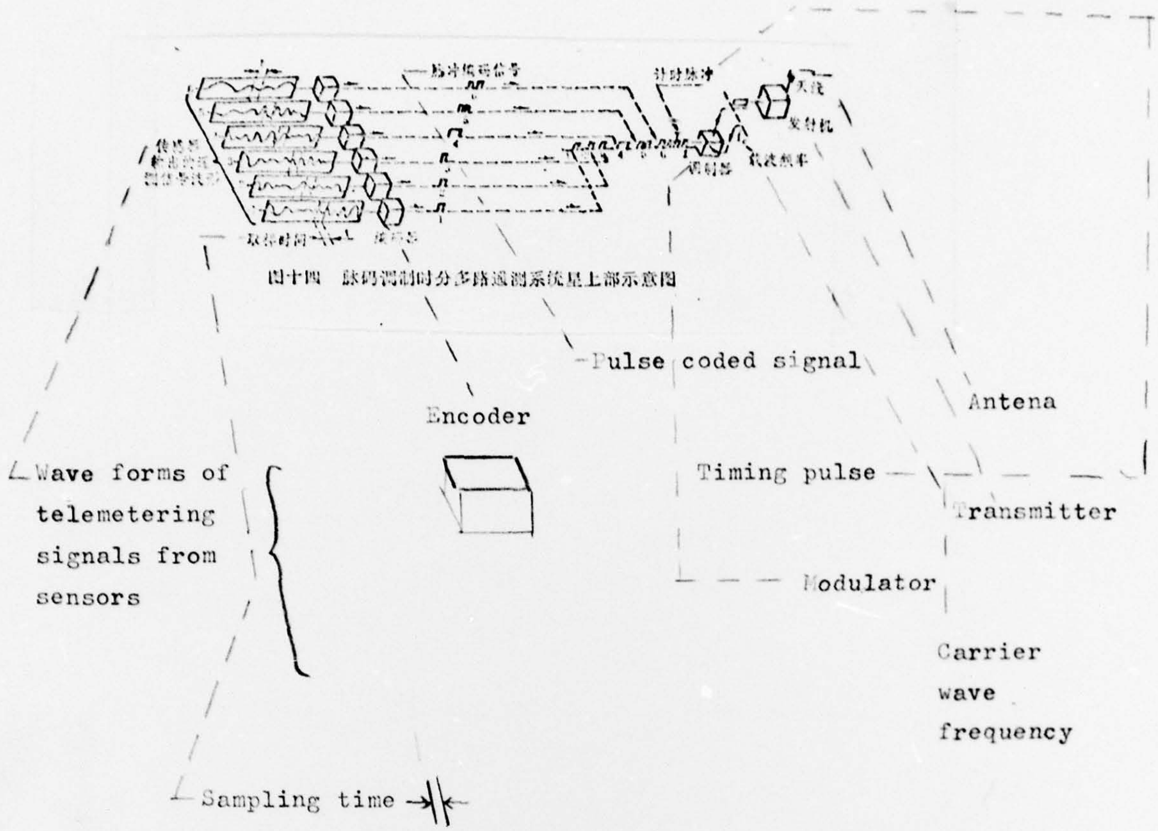


Fig. 14: Sketch diagram of the time discrimination multichannel telemetry system with pulse coded modulation on a satellite

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