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Frequency Response in Cerebral Palsied Children

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Frequency response test was employed to explain the servomechanism of cerebral palsy. Twenty cerebral palsied children were tested in comparison with normal subjects.

This test made it clear that cerebral palsied patients had their own servomechanism, stability of which, however, was either inferior to normal or so large to make the response sluggish.

Feedback system is said to be stable if, for small values of input, the output remains small or does not increase with time. If the output increases with time, this leads to oscillation and unstability. The question of stability is fundamentally transient in nature, and is related to the transient response of the closed loop system.

The transfer function of the closed loop is usually studied in terms of the sinusoidal steady state where concepts of phase and magnitude ratio are readily related to experiments. When a sinusoidal wave is applied in variable frequency to a network of linear elements as a input, the relation of input to output expressed by phase and magnitude ratio is considered to afford a transfer function of the network, and is of absolute value in determining characteristrics of self control system.

This is called frequency response test, and aids in determining whether human being has a stable feedback system or not[1)2)3)]. Frequency response test appealed to us as the most likely to explain the servomechanism of cerebral palsy. So, we examined frequency response in twenty cerebral palsied children in comparison with normal subjects.

METHOD

Fig. 1 shows the apparatus we constructed for experimental purpose. This consisted of two main parts, i. e., the target and operating element. Motion of target was generated by the energy of steel spring

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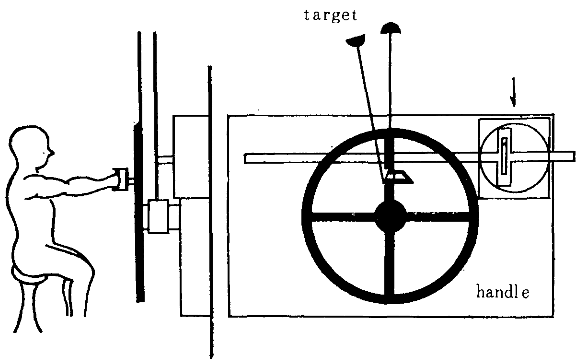
Fig. 1. Mechanical portion of apparatus



which provides a kind of rotary mòvement. Incorporation of a specific cam mechanism made it possible to convert rotary movement around rotary axis into pendulous one. As a result of this conversion a pendulum described a sinusoidal wave. Pendulous motion was altered in frequency by changing the size of governor s plane. Sampled frequencies were as follows: 0.05, 0.1, 0.15, 0.2, 0.3, 0.5, 0.15, 1.0, 1.5 and 2 cycles per second.

The seated subject was instructed to grip the handle of operating element and control its pointer so as to follow pendulous target. Since

Fig. 2 . Frequency response, normal

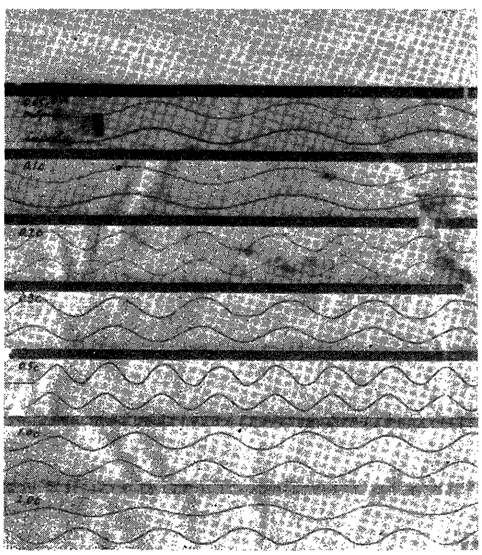
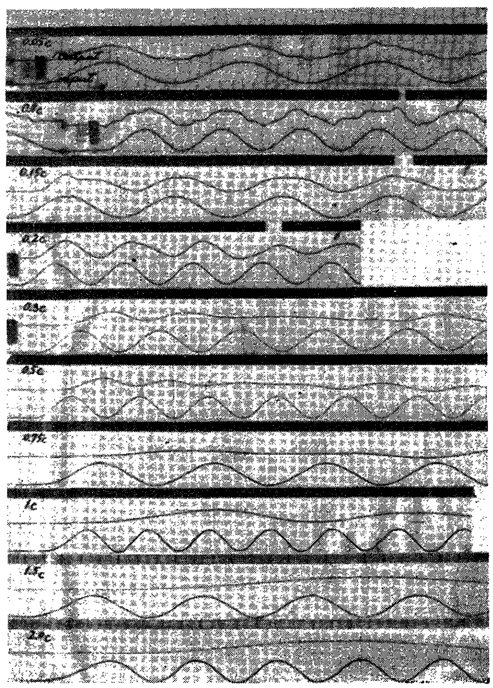


Fig. 2B Frequency response. C.P.



variable resistance attached to rotary axis of target and operating element was connected with D. C. circuits, cathode oscillogaph made synchronously possible both recordings of movement of target and operator.

Amplitude of pendulous motion was set up to indicate 40 degrees, and calibrated as standard. Thus, each movement of target and operator respresented input and output respectively. Fig. 2A shows an example of recording in normal persons. From this record we could readily obtain phase and magnitude ratio between input and output.

The phase and magnitude information were plotted in two ways: (1) With the logarithmic plots of frequency on abscissa, phase and magnitude ratio were separately plotted in ordinate., (2) With the semilogarithmic plots of frequency on abscissa, magnitude expressed in db, and angles of phase were concurrently plotted in ordinate. From this we obtained socalled Bode diagram which afforded us the stability criteria, i. e., phase margin (ϕ), gain margin (M), cross-over angle frequency, cross-over phase frequency, and natural frequency.

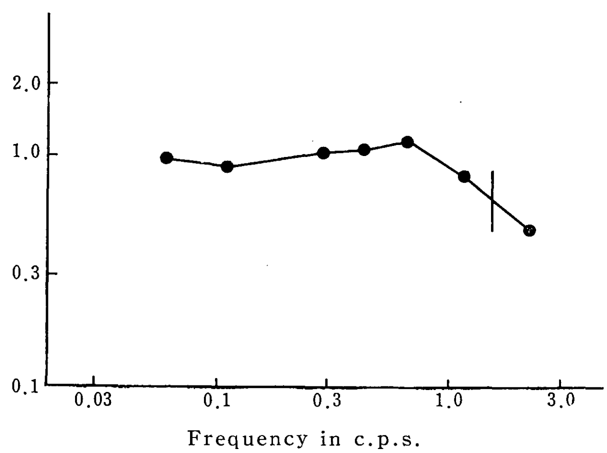
RESULTS AND DISCUSSION

Fig. 3 illustrates an example of gain curves in normal persons. An instance of gain curves obtained from cerebral palsy is displayed in Fig. 4.

There were seven of twenty patients tested in whom gain curves came within the normal limit. In six patients gain curves remained similar to normal persons within the certain range of frequency, but showed rapid fall with increased frequency. There were four instances where gain curves remained similar to normal ones merely within the confined range of both high and low frequencies.

In two cases, gain curves became far less than in normal over the whole frequency domain. There was another case where gain curve

Fig. 3. Frequency response gain data obtained from a normal person.



turned out higher than normal against whole freqnency domain. In brief, the deviation from normal gain curves was observed in thirteen of twenty patients varying with the severity of affection.

Fig. 5 and 6 represent each of phase curves derived from normal subject and cerebral palsied child. Seven of twenty patients tested disclosed plotting of phase closely similar to normal groups. In three cases phase was plotted in a manner similar to normal persons within the certain range of low frequency. There were ten patients whose phase lag became greater against each of frequencies. To sum up, augmented phase lag, more or less, depending upon the severity of clinical involvement was demonstrated in thirteen of twenty patients tested.

As the next step we shall turn to interpretation of the results obtained from Bode-diagram (Fig. 7, 8).

Fig. 4. Frequency response gain data obtained from a cerebral palsied girl.

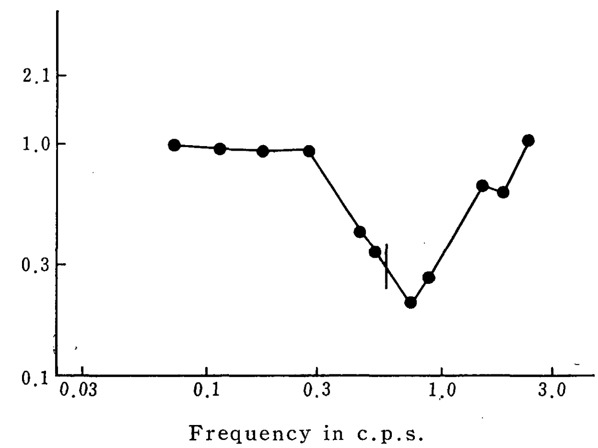
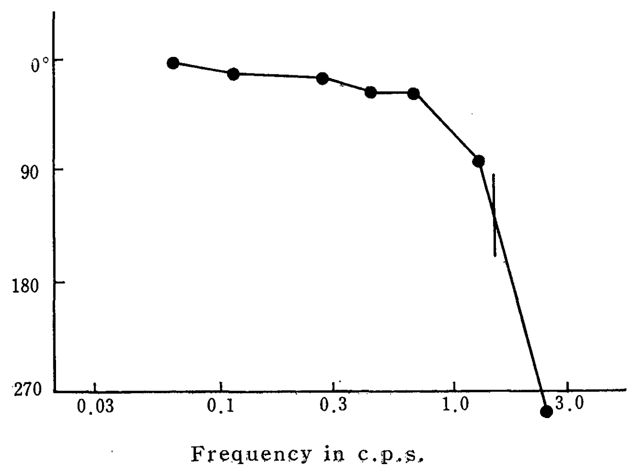


Fig. 5. Frequency response phase data obtained from a normal person



Cross-over angle frequency is represented by the certain frequency where gain curves cross over zero (db) level, and its value informs approximately us of velocity of response. The normal average value was 0.613 cycle ranging from 0.38 to 0.84 cycle. Cerebral palsied children, on the other hand, gave 0.446 c on the average. Cross-over angle frequency remained within the normal limit in twelve instances, and lower than normal in the rest.

As stated above, we can obtain the stability criteria of the system in terms of phase and gain margin, and we can be also approximately informed of shape in transient response by phase margin.

Normal persons disclosed 136 degrees of phase margin on the average amounting from 113 to 160 degrees. Cerebral palsy showed mean value of 119 degrees.

Fig. 6. Frequency response phase data obtained from a cerebral palsied girl.

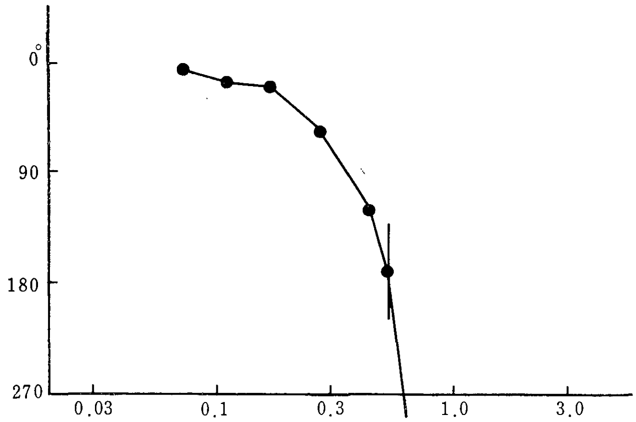
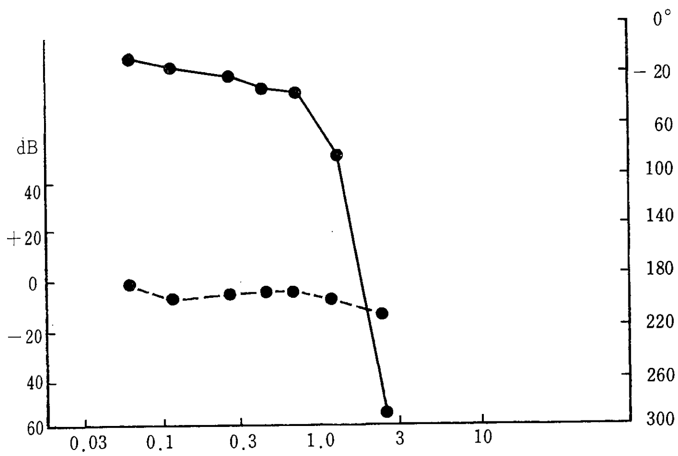


Fig. 7. Bode-diagram of a normal subject



There were eleven cases within the normal limit, seven cases less than normal, and one case more than normal. None revealed negative value of phase margin.

Normal gain margin was 5.08 (db) on the average ranging from 3 to 7 (db). Cerebral palsy came to an average of 4.6 (db) including fourteen cases within the normal limit and six cases out of normal range.

Cross-over phase frequency corresponds to the certain frequency where phase curves meet-180 degrees level. Normal value was 1.35 c on the average with the range of 1.05 to 1.7 c. Cerebral palsy gave 0.89 c on the average.

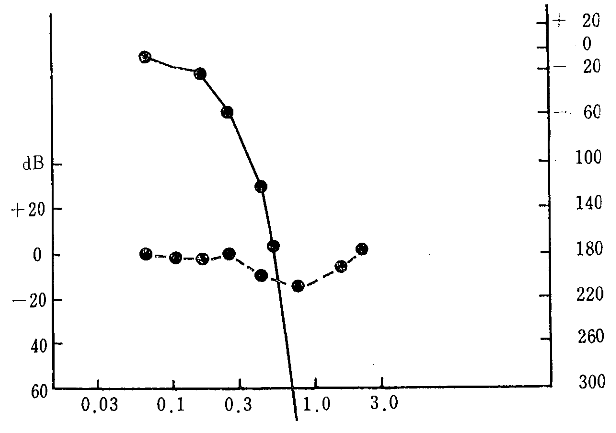
There were six of eighteen patients within the normal limit, and the rest without the normal limit.

Natural frequency is expressed by the certain frequency with which the system starts oscillating independently of input following the increased high frequency. In normal persons 1.16 cycle was given on the average with the range of 0.75 to 1.6 cycle. Cerebral palsy showed 0.664 cycle on the average, six cases within the range of normal value, and the rest far from normal limit. Natural frequency came out to be approximately corresponding to cross-over phase frequency in every subject.

A servomechanism design must meet two basic performance requirements. First, not only the output must respond with a minimum error for all the commands, but also react quikly and smoothly to all the input. Second, in order for the response to be well damped, it must be stable.

In order to meet the first requirement it is necessary to enhance sensitivity of control system. Overshoots or oscillations, however, occur when the sensitivity is too high. Thus, the first requirement comes into conflict with the second one.

Fig. 8. Bode-diagram of a cerebral palsied girl



Frequency in c.p.s.

The servomechanism design problem, therefore, resolves itself into the necessity for provision of sensitive control without allowing the oscillations.

From the standpoint of such basic view, we must explain the characteristics of control system in terms of deviation and stability. Deviation represents disparity between command and control variable. Zero deviation does not necessarily mean the satisfactory performance. Primary emphasis must be laid on the transient reponse.

In what way deviation e (t) persists with time (t), namely, shape of deviation following variation in command or load is a matter of primary importance.

It is desirable to make deviation zero with a minimum time delay and accelerate the velocity of response. If a response is allowed to increase in velocity unlimitedly, however, the system may as a rule become unstable, and the oscillation will build up rather than damp out. In this respect, it is of primary necessity to determine whether the control system is stable or unstable. "Stable" is represented by the transient phenomenon which attenuates following elapsing time and reaches steady state after the certain period. By "Unstable", on the the other hand, we mean that transient phenomenon remains unchanged or increases in oscillation with time and does not arrive in steady state. To make a decision on whether stable or not, therefore, is to make certain whether transient phenomenon damps out or not.

In this sense, stability criteria are of utmost importance. As already stated, Bode-diagram serves as sufficient stability criteria in terms of gain and phase margin.

The control system is defined to be stable or unstable depending on whether gain and phase margin are plus or minus. The more plus the margin, the more tendency for increased stability. Too much margin, however, makes the response sluggish.

Frequency response test is not complete unless the shape and velocity of transient response are studied concomittantly.

They are interpreted in terms of phase margin and cross over angle frequency respectively.

Phase margin and cross-over angle frequency inform approximately us of the shape and velocity in transient response respectively. Twelve of nineteen patients presented normal limit of values in cross-over angle frequency, so that they disclosed velocity of transient response comparable to normal persons. In the rest without normal limit there appears to be either too slow or fast transient response. Phase margin remained within normal range in eleven of nineteen patients whose shape of transient response is assumed to be like to normal one. It is noteworthy that more than half of cerebral palsy tested revealed as comparable transient response both in velocity and shape as normal subjects.

It is well established that human being is able to decrease its gain constant in proportion to increse of gain constant of controlled system before this is extremely so large that human being cannot cope with the situation.

In the presence of too large gain constant of controlled system human being cannot proportionally diminish its own gain constant. This is reported to lead enevitably to too large loop gain constant and result in a kind of steady oscillation.

Neither normal persons nor cerebral palsied patients was relieved from occurrence of oscillation at high frequency. It was called natural oscillation.

Frequency at the time of natural oscillation was lower than in normal in most of cerebral palsy. This indicates decreased capability of reducing the gain constant in cerebral palsy.

In the experimental situation where human being is assumed as one of selfcontrol system there is no need for identification of details in brain mechanism provided ruling law of input and output is made clear.

An investigative method by which a research is conducted with the idea of attempting to explain the internal structure in terms of characteristics in response is to a certain extent applicable to study of human central nervous system.

If one can succeed in unveiling some characteristics of the system, one can surmise the responsible structures much more correctly with the only aid of outward inspection. There is no denying the fact that it is difficult to interprete the central nervous system perfectly on the basis of characteristics because of its non-linear system. Admittedly, however, central nervous system is considered approximately as a linear system. We take this stand in the sense that cerebral palsy may also be explained in terms of characteristics in frequency response test. Bode digrams obtained from cerebral palsy disclosed that gain characteristics damped out with the increase of frequency.

This observation indicates admittedly that cerebral palsy has also an approximate linear system.

CONCLUSION

Authors have analyzed the movement of cerebral palsied patient's upper limbs from the view point of servomechanism.

The subjects were instructed to control the pointer so as to follow pendulous target in variable frequencies, and underwent the socalled frequency response test. This test resulted in revealing the various aspects of servomechanism of cerebral palsied patients in terms of phase and gain ratio between input and output.

The deviation from normal gain curves was observed in thirteen of twenty patients varying with the severity of affection. Augmented phase lag, more or less, was demonstrated in thirteen of twenty patients tested.

Cross-over angle frequency remained within the normal limit in twelve instances, and lower than normal in the rest.

Six of eighteen patients tested presented normal limit of values in cross-over phase frequency.

Phase margin showed 119 degrees on the average, eleven cases within the normal limit, seven cases less than normal, and one case more than normal.

Gain margin came to an averge of 4.6 (db) including fourteen cases within the normal limit and six cases out of normal range.

REFERENCES

1) IIDA M. and KOBAYASHI M. : Servoanalytic Study of Eye Tracking Movement recorded by Electro-oculography. Nagoya Journal of Medical Science **26** : 28, 1963.
2) STARK L. and BAKER F. : Stability and Oscillations in a Neurological Servo-mechanism. J. Neurophys., **22** : 156, 1959.
3) STARK L., IIDA M. and WILLIS P. A. : Dynamic Characteristics of the Motor Coordination System in Man. Biophy. J. **1** : 279, 1961.