ROBUST CONTROL OF THE DUPLEXCAVITY FREQUENCY STABILIZATION SYSTEM FOR A 20MEV LINAC

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Abstract

The pulse power at the entrance of a LINAC is increased by the positive power feedback.If we would like to obtain a beam with variable energy,it is necessary to change the output power and oscillation frequency of the pulse magnetron.The unstability caused by the positive power feedback and the variable output power of the magnetron bring about obvious change and unstability in the power spectrum.They will cause a change of the working frequency defined by the duplexcavity discriminator,and consequently have influence on the dose rate and its stability.In order to overcome the fault,we can cut off a part of the dose rate to preserve the stability of the effective dose rate and use the cut off dose rate to define the working frequency of the magnetron.A mechanical method is used to sweep over the mean resonant frequency of the duplexcavity from a fixed original value until a frequency which provides the cut off dose rate corresponding to a preset value is reached.This frequency is locked as the working frequency and the LINAC works normally.

I. Introduction

The energy of the electron beam of a LINAC whose power source is a 5MW pulse magnetron is increased over 20MEV through the power feedback .But the positive power feedback enhances the reflection of the microwave system,as a result ,the spectrum form of the pulse magnetron is changed and becomes unstable.It causes a change of the working frequency defined by the duplexcavity discriminator,then the beam intensity will be decreased until it becomes less than the desired value.In order to overcome the trouble,a robust control is introduced.In this system,the stabilized oscillation frequency of the magnetron is not preset but determined by the desired beam intensity.

II. The Method of Frequency Stabilization with a Duplexcavity

We can treat the duplexcavity discriminator consisted of two cavities with different resonant frequencies as a frequency standard.The oscillation frequency of the pulse magnetron is stabilized by a frequency stabilization system nearby the point of intersection of the combined resonant frequency curve at the frequency axis,it is the principle of frequency stabilization with the duplexcavity.

A frequency discriminator circuit is shown in Fig.1.The comparator sends a DC signal in direct proportion to the magnitude of the frequency deviation and a pair of controlling signals indicating the direction of the deviation. A stepping motor servo which is controlled these two signals mentioned above tunes the pulse magnetron to perform the frequency stabilization.In practice,the output of the comparator with respect to the oscillation frequency of the magnetron corresponds to the discrimination curve of the duplexcavity:

$$P(w_b,w_a)=\frac{KG^2}{4}\left(\frac{1}{(w_b-w)^2+\frac{G^2}{4}}-\frac{1}{(w-w_a)^2+\frac{G^2}{4}}\right) \tag{1}$$

where w_b and w_a are the resonant frequencies of the two cavities respectively,K is a constant.When $Q_b=\frac{w_b}{w_b-w_a}$, $Q_a=\frac{w_a}{w_b-w_a}$ and $G=w_b-w_a$ (Q is the quality factor),$P(w_b,w_a)$ is an optimal curve.If $w_a\leqslant w\leqslant w_b$, then

$$\frac{dP(w_b,w_a)}{Kdw}=\left(\frac{G^7}{16}+G^3(w_b-w)(w-w_a)\left(\frac{G^4}{4}+(w_b+w_a-2w)^2+(w_b-w)(w-w_a)\right)\right)/2\left((w_b-w)^2+\frac{G^2}{4}\right)^2\left((w-w_a)^2+\frac{G^2}{4}\right)^2 \tag{2}$$

$dP(w_b,w_a)/dw$ has a maximum at $w=(w_b+w_a)/2$, the discrimination sensitivity is highest(the discrimination curve is shown in Fig.2)[1].

A stepping motor servo is shown in Fig.3.The output of the VCO drives the reversible ring divider(LO52) whose shifting direction is controlled by the outputs of the comparator Y_1Y_2. The outputs of the divider after amplification drive the stepping motor to tune the pulse magnetron.

The frequency stabilization system is a pulse control system, the block diagram and the signal flow graph of this system is given in Fig. 4.The gain K_0 includes these of the discriminator,the pulse amplifier and the comparator.The transfer functions of the zero-order holder and the stepping motor servo can be expressed respectively as $(1-e^{-sT})/s$ and $F(s)=K_1/(s+R_L/L_m)(s^2+2qW_ns+W_n^2)$ (3)

where constant K_1 is an equivalent gain of the stepping motor servo,R_L,L_m,q and W_n are the series resistance,winding inductance,damping factor and natural frequency of the motor.T is the working period of the pulse power source. The frequency shifting factor N(t) which is a ramp function approximately is caused by the change of ambient temperature.If we would change the oscillation frequency of the magnetron by preset the resonant frequencies of the two cavities,the input V(t) is not equal to zero but a step function,then the steady-state error of the system is zero.The principle of adjusting frequency with a mechanical method is shown in Fig.5.The resonant frequencies of the two cavities will be adjusted to the preset values which correspond to the stepping number of the motor to decide the oscillation frequency of the magnetron.When the high voltage on the magnetron is fallen,the stepping motor will run reversibly to adjust the tuning bars of the two cavities to the original positions[2].

III. Robust Control of Frequency Stabilization System

For a control process which is disturbed,some parameters of the controlled plant are perturbed.For instance,the oscillation frequency of the magnetron fixed by the frequency stabilization process is affected by the spectrum form of the magnetron,then the intensity of the electron beam will be descreased even to a value less than the desired value.In order to overcome the fault mentioned above,I have designed a closed-loop control which has a rapid transient response process and a good following performance for all reference values,this control is referred to as robust control.

The general form of a robust control system is shown in Fig.6.The system is stabilized by a stabilizing compensator.A servo compensator has preserved the output of the controlled plant to

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follow the reference value which corresponds to a desired oscillation frequency of the magnetron rather than a preset average resonant frequency of the two cavities. This reference value is decided by a preset beam intensity. Since the beam intensity has a single maximum with respect to the oscillation frequency, a sweeping method of the average resonant frequency from a fixed original value by a stepping motor is adopted. When the beam intensity which is denoted by the average value (dose rate) of the output voltage on the ionozation chamber has just got over a preset value, the sweep is stopped automatically. In order to stabilize the effective beam, a pick-off technique which cut off the excessive part of the effective beam is introduced, the effective beam is then stabilized even though the excessive part is unstable[3].

A circuit which provides the mentioned above is shown in Fig.7. A nonperiodic switching signal from the beam cut off circuit has controlled the current source to charge a capacitor with a parallel potentiometer. When the voltage on the capacitor has increased to a preset threshold value, transistor T turns on, a signal is sent to stop the stepping motor which tunes the duplexcavity, then the oscillation frequency of the magnetron is stabilized nearby the average resonant frequency of the duplexcavity fixed by the stepping motor. In this robust control system, the stabilizing compensator is omitted, the servo compensator contains two integrators: the ionization chamber and the RC integrator. The pulse transfer function of the controlled plant (it is the frequency stabilization system) is written as follows.

$$T^*(s)=K_1K_0((1-e^{-sT})/s(s+R/L_m)(s^2+2qw_ns+w^2))^*/(1+K_1K_0((1-e^{-sT})/s(s+R/L_m)(s^2+2qw_ns+w^2))^*) \quad (4)$$

From Fig.4, we can obtain the state equation and output equation of the controlled plant as follows:

$$X(k+1)=\begin{vmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -h/p & -q/p & -f/p \end{vmatrix} X(k)+\begin{vmatrix} 0 \\ 0 \\ 1 \end{vmatrix} v(k) \quad (5)$$

$$y(k)=\begin{vmatrix} d/p-ah/p^2 & c/p-aq/p^2 & b/p-af/p^2 \end{vmatrix} X(k)+av(k)/p \quad (6)$$

where $a=K_1K_0w_n^2\sqrt{q^2-1}$, $b=-K_1K_0((R^2/L_m^2-2qw_n^2)\sqrt{q^2-1}\,e^{-RT/L_m}+((\sqrt{q^2-1}R^2/L_m^2-4qw_nR\sqrt{q^2-1}/L_m+2w_n^2\sqrt{q^2-1}\,Rw_n(2q^2-1)/L_m)\mathrm{ch}Tw_n\sqrt{q^2-1}+Rq(R/L_m+2w_n\sqrt{q^2-1})/L_m\cdot \mathrm{sh}Tw_n\sqrt{q^2-1})e^{-Tw_nq}$, $c=K_1K_0((R^2/L_m^2-2qw_nR/L_m+w_n^2)(e^{-Tw_nq}+2e^{-TR/L_m})\sqrt{q^2-1}\,e^{-Tw_nq}+R(2qw_n-R/L_m)\sqrt{q^2-1}/L_m-R(1+e^{-RT/L_m})((R\sqrt{q^2-1}/L_m+w_n(2q^2-1))\mathrm{ch}Tw_n\sqrt{q^2-1}-q(R/L_m+2w_n\sqrt{q^2-1})\mathrm{sh}Tw_n\sqrt{q^2-1})e^{-Tw_nq}/L_m)$, $d=K_1K_0\cdot(R(R\sqrt{q^2-1}/L_m+w_n(2q^2-1))\mathrm{ch}Tw_n\sqrt{q^2-1}/L_m-Rq(R/L_m+2w_n\sqrt{q^2-1})\mathrm{sh}Tw_n\sqrt{q^2-1}/L_m-(R^2/L_m^2-2qRw_n/L_m+w_n^2)\cdot\sqrt{q^2-1}\,e^{-Tw_nq})e^{-(RT/L_m+Tw_nq)}$, $p=(K_1K_0+(R^2/L_m^2-2qw_nR/L_m+w_n^2)R/L_m)w_n^2\sqrt{q^2-1}$, $f=(R^2/L_m^2-2qw_nR/L_m)(K_1K_0+Rw_n^2/L_m)\sqrt{q^2-1}\,e^{-RT/L_m}+(Rq(R/L_m+2w_n\sqrt{q^2-1})\cdot \mathrm{sh}Tw_n\sqrt{q^2-1}/L_m+(2(w_n^2R/L_m+K_1K_0)(R^2/L_m^2-2qw_nR/L_m+w_n^2\sqrt{q^2-1}-RK_1K_0(R\sqrt{q^2-1}/L_m+w_n(2q^2-1)))\mathrm{ch}Tw_n\sqrt{q^2-1})e^{-Tw_nq}$, $g=(e^{-2Tw_nq}+2e^{-(Tw_nq+RT/L_m)})(R^2/L_m^2+w_n^2-2qw_nR/L_m)(K_1K_o+Rw_n^2/L_m)\sqrt{q^2-1}+R(2qw_n-R/L_m)\sqrt{q^2-1}/L_m-R(1+e^{-RT/L_m})((R\sqrt{q^2-1}/L_m+w_n(2q^2-1))\mathrm{ch}Tw_n\cdot\sqrt{q^2-1}-q(R/L_m+2w_n\sqrt{q^2-1})\mathrm{sh}Tw_n\sqrt{q^2-1})e^{-Tw_nq}/L_m$, $h=(R^2/L_m^2-2qRw_n/L_m+w_n^2)(K_1K_o+w_n^2R/L_m)\sqrt{q^2-1}\,e^{-(RT/L_m+2Tqw_n)}+K_1K_0R((R\sqrt{q^2-1}/L_m+w_n(2q^2-1))\mathrm{ch}Tw_n\sqrt{q^2-1}-q(R/L_m+2w_n\sqrt{q^2-1})\mathrm{sh}Tw_n\sqrt{q^2-1})e^{-(RT/L_m+Tw_nq)}/L_m$.

The relationship between the change of the oscillation frequency of the magnetron and the cut off part of the beam is linear approximately, so we can obtain a result as follows:

$$\lim_{k\to\infty}(y(k)-y_r(k))=\lim_{z\to 1}(1-z^{-1})Y_r(z)/(1+2Tz^{-1}(a+bz^{-1}+cz^{-2}+dz^{-3})/(1-z^{-1})^2(p+fz^{-1}+gz^{-2}+hz^{-3})) \quad (7)$$

when $Y_r(z)=K_2/(1-z^{-1})$, then $\lim_{k\to\infty}(y(k)-y_r(k))=0$.

IV. Conclusion

This robust control system is successful as the emission current of the electron gun is stable. The sweep time of the stepping motor used to decide the oscillation frequency of the magnetron only depends on the response time of the ionization chamber.

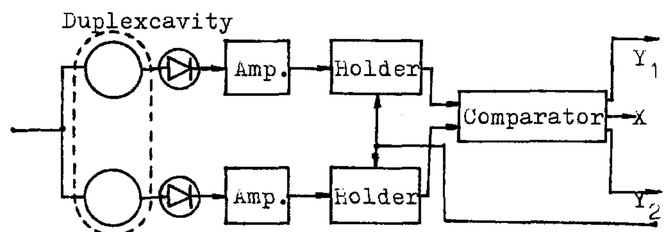

Fig. 1

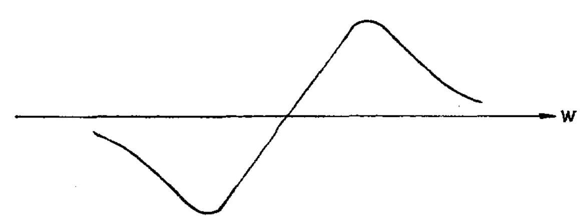

Fig. 2

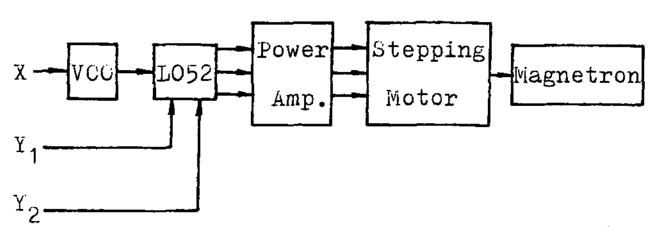

Fig. 3

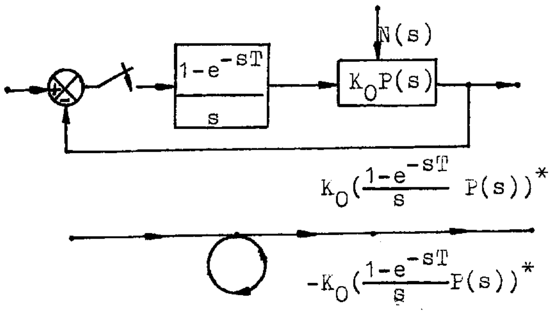

Fig. 4

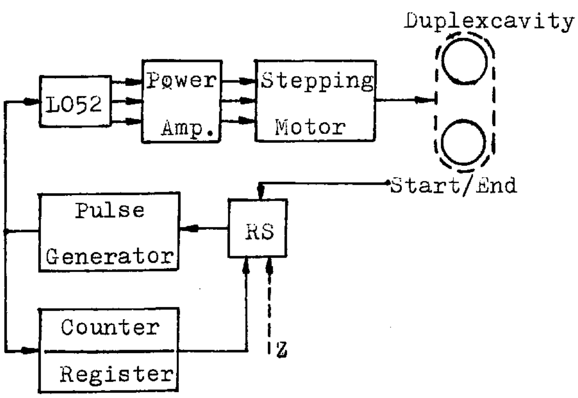

Fig. 5

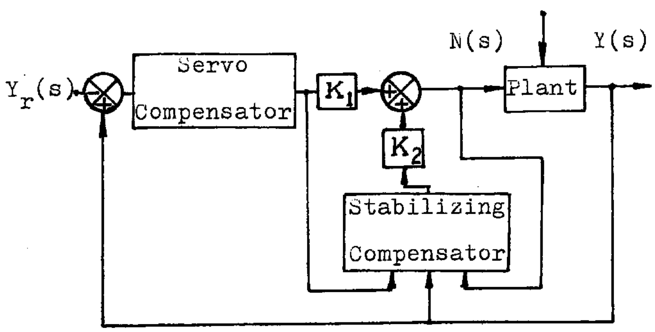

Fig. 6

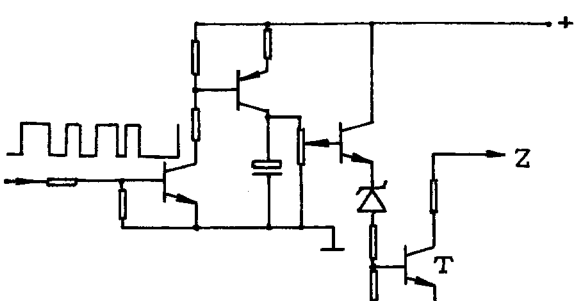

Fig. 7

References

1. Xi De-xun, Zeng Yen, Wen Yu-lin, "Particle Accelerators"—Proceeding of 1979 Accelerator Conference, pp.197. (in Chinese)

2. Xi De-xun, Proceeding 2nd Particle Accelerator Conference, Shanghai, Nov.1982. (in Chinese)

3. E.J.Davison and A.Goldberg, Automatica, Vol.11, pp.461, 1975.