NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. IT
has been reproduced from the best available
copy to permit the broadest possible avail-
ability.

SLAC-TI--84-4

DE84 009414

**STABILITY OF KLYSTRON OPERATION
AS A FUNCTION OF INPUT PARAMETERS***

AMARJIT SINGH

Central Electronics Engineering Research Institute

Pilani, Rajasthan, India

and

Klystron Department, Stanford Linear Accelerator Center

Stanford University, Stanford, California 94305

GERHARD T. KONRAD AND CHARLES GRIFFIN

Klystron/Vacuum Department, Stanford Linear Accelerator Center

Stanford University, Stanford, California 94305

Abstract

Instabilities in the operation of a high-power multicavity klystron have been studied as a function of various input parameters. Among these, the focusing magnetic field, rf input power and tuning of the second harmonic cavity were observed to have a striking effect in deciding the regions of unstable operation.

One region of instability could be identified with a value of magnetic field corresponding to cyclotron resonance, at the operating frequency. The magnetic field value in the region of the input end, and the second harmonic cavity, was found to have a more decisive influence on stability, than the magnetic field at the output end.

A hysteresis effect has been associated with the instabilities. This could be explained in terms of multipactor phenomena.

These observations indicate, among other things, that in designing new tubes, it might be desirable that the operating magnetic field stay well away from cyclotron resonance conditions, especially in the gun region, and the cavities at the input end. The experimental techniques can be used for optimizing the operating conditions of existing tubes.

MASTER

* Work supported by the Department of Energy, contract DE-AC03-78SF00515.

1. Introduction

In high power multicavity klystrons an axial magnetic field is used in order to keep the electron beam focused in its progression through the sequence of cavities. The parameters most commonly watched are the linkage of magnetic flux with the cathode and the ratio of the magnetic field in the rest of the tube to the Brillouin field.

These are important parameters in the static design of the electron gun and the focusing properties of the electron beam.¹ The above mentioned ratio has also been used as the parameter defining the magnetic field in dynamic studies which consider the lateral as well as longitudinal motion of electrons.^{2,3}

In the case of rising-sun magnetrons, which have a zero order component rf field present along with the π mode, it is known that the efficiency of operation drops at magnetic fields which correspond to cyclotron resonance.⁴ The cyclotron resonance there interferes with the normal trajectories of electrons moving in the interaction space.

In the case of high power klystrons, lateral movement becomes quite significant as a result of bunching and of space charge forces. It may therefore be expected that any independent cumulative effect, such as cyclotron resonance, may have a significant impact on the trajectories and interfere with normal operations.

Another phenomenon which can cause variations in power output as a function of the magnetizing field is that of multipactor. It occurs when the dc and rf field are such that electrons strike one or more surfaces repeatedly while they gain energy in transit and release secondary electrons at each impact. If the secondary emission coefficient is greater than one for the given energy of the arriving electrons, the oscillating space charge builds up rapidly.⁵ This space charge has the effect of inducing additional rf currents into the cavity. This has the effect of tuning the cavity and also of absorbing

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

some of the power. Different modes of multipactor exist in which there is an integral relationship between the transit time and half the period of rf oscillation.

An objective of this investigation was to gain a better understanding of both these types of phenomena, which can interfere with clean operation at higher power levels.

The klystron studied had been developed at the Stanford Linear Accelerator Center⁶ for use in the positron and electron project (PEP). Its magnetic field is generated by a set of ten coils. Current in these could be varied collectively or individually. This provided flexibility in controlling the magnetic field and its profile. A cross-section of the tube is shown in Fig. 1.

It is a CW tube with a power output of 500 KW. Efficiency being an important consideration, a second harmonic cavity has been incorporated into the design, as cavity number three, out of a total of five cavities.

In the experimental setup, an X-Y recorder was used in conjunction with a variety of measuring instruments to draw a series of curves, covering a wide range of operating parameters. The operation was studied as a function of magnetic field, operating voltage, rf drive level, and tuning of the second harmonic cavity, *et cetera*, which served as parameters for the curves.

As the rf drive power fed into the input cavity was progressively increased, well-defined thresholds of instabilities were observed at certain values of magnetic field. Studies were made in which magnetic field was left constant in certain regions and varied in others, so as to localize the causes of the observed effects.

There are pick-up probes located in the different cavities. The output from these was also studied as a function of the magnetic field. This helps to correlate the observations with the phenomena occurring in the individual cavities.

Simultaneous measurements of power output and residual pressure inside the tube were made while varying the focusing field. Correlations with instabilities were studied.

2. The Experiential Setup

The measurement system has provisions for determining thermal dissipation in different parts of the tube. These cover a variety of overload situations, or overheating of various parts, such as cavities, collector, *et cetera*.

The rf power is measured by thermistor-bridge type instruments, which can be connected to different probes. There is also a calorimetric measurement of heat dissipation separately in the input cavity, the output cavity (together with the output window and the drift space between the output cavity) and the collector. The initial measurements were made with the calorimetric setup. The later sets were taken with the help of a thermistor-bridge instrument whose recorder output was connected to the Y-axis of an X-Y recorder. The X-axis was fed from a resistor in the path of the current flowing through those coils whose field was being scanned through a range of values. This made it possible to scan through the field values in a relatively short period each time. Hysteresis effects, as between rising and falling values of field current, could be easily identified. While calibration of values was done occasionally, it was not done at the start of every set of curves. This does not affect the overall nature of the phenomena observed in a wide ranging survey, which covers a matrix of many variables indicated above.

Frequency spectra were recorded at specific points, especially when there was a change over from one kind of behavior to another. Output from the second harmonic cavity was also observed on a spectrum analyzer. Time variations in output were recorded, especially where there was a region of instability. Occasionally checks were made, by momentarily shutting off the heater supply so as to make a distinction between hum originating from the filament supply and fluctuations due to phenomena occurring in the interaction space.

The magnetic field had earlier been plotted for the given set of coils connected in series. A typical distribution is shown in Fig. 2. The magnetic field under different experimental conditions was estimated from those measurements by interpolations. It is to be noted that at a given value of current passing through all the coils, the magnetic field at all points is not the same. In particular, there is a large variation in the region of the cathode and at the near end of the collector. Consequently the cyclotron resonance value of magnetic field would be given for different regions with somewhat different values of current. This difference could be large for the end regions. The magnetic field in the median plane of each coil is also influenced by the current in the neighboring coils, especially the adjacent ones.

In the experiments the current through coils number three to ten was varied in different combinations or altogether. The current through the bucking coils, (i.e., coils number one and two, near the cathode region) was however kept at a constant value so as to ensure that as far as the beam formation in the gun region is concerned, it might not be disturbed.

There is spillover of the field due to the bucking coils into the region of cavities number one and two. As a result of this the magnetic field in the region of cavities one and two was not proportional to the current in the other coils, namely three, four, five, *et cetera*. The calculations of the magnetic field were suitably adjusted in order to take into account this constant magnetic field.

Cyclotron resonance depends upon the effective mass of the electrons, and consequently on the anode voltage (V_0). From the foregoing it is seen that the value of magnetic field required for cyclotron resonance, and that of the focusing current, would be dependent on some of the other parameters, such as anode voltage, location of resonance region in the tube, current distribution through the coils, *et cetera*.

However, for most of the measurements, the relativistic correction was small and the current through coils numbers three to ten (I_{mag}) was used as an independent variable. In this case the cyclotron resonance was estimated to occur at $I_{mag} = 16$ A for the region of cavity number one, assuming the rest mass for the electrons.

In order not to overstress the tube, when the magnetic field and input rf drive power (P_{in}) were varied over wide ranges, the anode voltage was initially kept at lower values than the normal operating value of 60 KV. Instabilities were also more prominent at some of the lower values. Later on data was also taken at 57 KV with a reduced range for the other variables.

3. Experimental Results

The operation of the klystrons depends upon a matrix of input parameters. The variable parameters were chosen successively so as to study their effects in conjunction with other parameters of interest. The first set of data refer to the case where all the coils except one, two were connected in series. Subsequently, the currents were varied independently, so as to localize the effects of resonances.

3.1 REGIONS OF REDUCED POWER OUTPUT

In the first experiments, where sharp changes in output were observed as a result of variation of current (I_{mag}) in coils number three to ten, the plotting of different parameters was done point by point. In this case, apart from the power output, the rise of temperature, ΔT , of the cooling fluid going to the collector, and separately into the last drift tube and the output cavity, was also plotted. All these curves are shown in Fig. 3.

It is noticed that there is a sharp reduction in the output power at 15.6 A and an upswing at 17 A as the current I_{mag} is raised. Correspondingly, the dissipation in

the collector rises in this region. The ΔT for the drift tube region and that for the output cavity area are not affected to the same extent. (It is to be recalled that within experimental error a current of 16 A through the coils corresponds to a magnetic field at the input cavity which would give cyclotron resonance at the operation frequency).

Apart from this region where there are sharp changes, there is also another one at lower current in the range of 11.5 A. Here, as the current rises beyond 11.5 A the power output suddenly falls and also the collector temperature rises. Below this value of current the heating of the output cavity and the nearby tube is considerably higher as shown by the ΔT_{rf} curve. The dip in power is at a current approximately two thirds of the current for the dip mentioned previously. This additional dip could be attributed to a different mode of resonance in multipactor phenomena.⁷

3.2 HYSTERESIS PHENOMENA

In Fig. 4 the power output from the klystron is plotted against the current through coils number three to ten, with anode voltage as parameter at 34 KV and 38 KV. In these and subsequent figures the plotting was done semiautomatically on an X-Y recorder, as explained earlier. It is seen that in the vicinity of 16 A there is a dip which has the following characteristics: between 16 and 16.25 A the curves for increasing and decreasing I_{mag} coincide; however, hysteresis is present between 16.25 and 17.6 A. The changeover point at 16.25 A is presumably the cyclotron resonance point.

3.3 PICKUP FROM CAVITIES

The curves in Fig. 5 show the variation of power output as well as the pickup from the probe in the second harmonic cavity (number three) versus the current I_{mag} through coils number three to ten. The figure also shows that the peak between 13.2 and 14.5 A does not show up in the pickup from the cavity number three, which indicates that this resonance is due to phenomena taking place in some other region.

It is seen also that the variation of the pickup from the probe in the current range 16.5 to 18.5 A is similar to the shape of the curve shown for a similar pickup versus resonance frequency of second harmonic cavity.⁶ Figure 6, taken from Ref. 6, shows the curve as well as the variation of power output versus mechanical tuning. The similarity of shape of the pickup curve points to a phenomenon of electronic tuning, such as by space charge.

Pickup from cavities number one to four (cavity five does not have a sampling probe) is shown in Fig. 7 as a function of I_{mag} . In this it is noticed that the resonance in the region of 13.5 A shows up in cavities number two and four and not in the second harmonic cavity. Furthermore, it is seen that a hysteresis phenomenon is observed in the pickup from cavities number one, two and four, as well. In the region of $I_{mag}=17$ A it is seen that the pickup is higher on the increasing I_{mag} curve than for the decreasing I_{mag} curve. These changes correspond to changes in opposite direction as regards power output. The reverse is true for the case of the hysteresis observed in the region of $I_{mag} = 12$ A. The pickup in the second harmonic cavity is sharply peaked in the region of 17 A (as also seen in Fig. 5), whereas that for the other cavities has a flat peak.

3.4 EFFECTS OF RETUNING THE SECOND HARMONIC CAVITY

Figure 8 shows the curves for power output versus I_{mag} when the second harmonic cavity has been retuned to a frequency of 696.508 MHz; that is, to a lower than normal frequency. In this case it is observed that on the curve for a decreasing value of I_{mag} , in the region of 17 A, the power output stays nearly constant at a level higher than for rising I_{mag} . At a critical value it falls suddenly. The value of I_{mag} at this sharp transition point is slightly higher for the higher values of anode voltage.

The ratio of the relativistic mass at 38 KV versus 32 KV is 1.015, and within experimental error, it is also the ratio of the above mentioned critical values of I_{mag} at

the two voltages. This agreement between the two ratios is indicative of the possibility that relativistic effects are showing up in the sharply defined resonances.

Figure 9 shows the power output versus I_{mag} at different values of anode voltage, with the second harmonic cavity tuned to a frequency of 708.132 MHz, which is higher than the normal value. In this case it is seen that in the region $I_{mag} = 17$ A on the upward going curve, the power output falls practically to zero for all the anode voltages. Furthermore, on the return path the power output rises above the value that it reached at higher values of focusing current. Also, there is a dip in the output at 16 A. Below 15 A there is very little hysteresis. The region around 13 A shows a pronounced peak.

The question arises as to why there is hysteresis in certain regions of I_{mag} and not in others, and what is the reason for the kind of changes observed around 16 A. A possible explanation is that in the region of hysteresis there is a different multipactor mode in the two branches of the curve in the sense that the transit time is a different multiple of $T/2$. It is also conceivable that as multipactor starts in any given mode, depending upon the value of the magnetic field at which it starts, it would tend to continue in the mode because the bunches having been formed in a certain phase and then having been multiplied in that phase, they will continue in that very phase.

In the vicinity of 16 A which is also the region of cyclotron resonance, it is conceivable that below the resonance magnetic field the phase of the multipactor is different from what it is above this magnetic field.

Another possibility is the presence of space charge, which can give an additional field superimposed on that caused by the cavity and the normal beam. The levels of residual gases can be another issue to consider, as has been done in a subsequent section.

3.5 THRESHOLD FOR INPUT RF DRIVE POWER

Figure 10 gives two sets of curves which show the variation of power output as a function of current through coils number three to ten at different values of drive power. It is seen that the threshold is very sharp for the dip in power output that appears in the vicinity of $I_{mag} = 16$ A. While for 5.7 W drive there is no dip in power in the region between 15.7 A and 17 A at 5.8 W drive it suddenly appears (in the figure the curve has been given for 6.0 W drive for convenience in showing separate lines).

The sharpness of threshold could be explained by the hypothesis that there is multipactor in this region, which requires the electrons to strike the surface with a certain minimum voltage so as to give a secondary emission coefficient greater than one.

It is seen that in this curve the hysteresis in the region 11.4 to 12 A is of opposite nature to the one seen between 15.7 and 16.7 A. In other words, the output power is higher on the upward curve in the former case and on the downward curve in the latter case. This could also be attributed to the different modes of multipactor in the two cases. Furthermore, at power drive levels of 2 to 3 W, the power output level is fairly constant throughout the range of variation from 11 to 20 A, whereas when the power output goes to 4W and above, there is a trough between 11.75 and 17 A.

This would indicate that there is a very broad resonance with a threshold between 3 and 4 W of drive which creates this trough and also that there are other resonances which are associated with the region 16 to 17 A for which the threshold lies at 5.75 W drive level.

In one set of experiments the threshold drive level for introducing the instability in the region of $I_{mag} = 16$ A was studied as a function of anode voltage. As seen in Fig. 11, the drive threshold decreases with increasing voltage. It is 5.2 W for 55 KV and 6.6 W for 40 KV anode voltage.

Figure 12 shows the power output versus I_{mag} right near the threshold for an anode voltage of 45 KV. It is seen that on the upward swing there is a two-peak resonance curve between 15.5 and 17 A, whereas on the return path this variation is smoothed out. (There is a transition also at 18 A.) This would seem to indicate that on the increasing I_{mag} curve there are sharp changes in phase of the perturbing space charge cloud as one goes from magnetic fields below cyclotron resonance to higher ones. These different phases could be for multipactor space charge or for the perturbation on the main electron beam. For the decreasing I_{mag} curve a different multipactor mode is assumed. The residual pressure is also higher as shown subsequently.

3.6 REPRODUCIBILITY OF CURVES

In order to see the reproducibility of the curves and of the transition points, curves were redrawn on the same chart in different runs. Figure 13 shows two sets of such curves for $V_0 = 57$ KV. It is seen that the curves and transitions are fairly reproducible. This is particularly true in the region of $I_{mag} = 16$ A, which corresponds to cyclotron resonance. This would indicate that the phenomena are precisely controlled at this value of magnetic field by cyclotron resonance. This shows that the associated phenomena are precisely determined by electron beam interaction or by multipactor. Any changes caused by phenomena such as release of gases would have tended to be less sharp and more variable from run to run, depending upon rate of change of I_{mag} . Small variations among sets of curves at I_{mag} greater than 18 A could be attributed to such effects. There are two peaks and a trough as in the case of Fig. 12. in the region 15.5 to 17.5 A. There is also an additional peak at 19.75 A and other troughs at 21 and at 26.25 A.

Figure 14 shows the power output versus I_{mag} for different values of drive power to considerably higher levels, namely from 10 W to 24 W. It is seen that as one goes to higher drive power levels, the troughs in the power output widen. Also more than one

trough having different hysteresis curves appear at higher drive levels. These could be attributed to different modes of multipactor; however, in the region from 16 to 16.5 A all of the curves nearly coincide both on the upward and the downward swing of I_{mag} for all values of input drive power. This again is the region of I_{mag} which corresponds to the field for cyclotron resonance.

3.7 LOCALIZED VARIATION OF MAGNETIC FIELD

Figure 15 shows variation in power output when current in coils three, four, five and six is kept constant, and that in coils seven, eight, nine and ten is varied. It is seen that the variations in P_0 are relatively small. This is indicative of the fact that the phenomena causing sudden changes with focusing current are lying essentially near the input end of the tube.

Figure 16 shows the power output when current in coils seven to ten is kept fixed at 20 A and that in coils three, four, five and six is varied.

The input drive level is set at 5 W, 10 W and 15 W, respectively. It is seen that at 5 W there are no striking changes, except a general rise in P_0 , as the focusing current rises. There is also no hysteresis. With higher levels of drive, a trough appears above 16.5 A, whose width increases with drive level. Hysteresis also appears around 24 A. Comparing these data with those of the previous figures confirms that the cyclotron and multipactor resonances are having their major influence in the regions of cavities number one, two and three.

Effects of varying the current in coil number three, (I_3), which is over cavity number one, are given in Fig. 17. The current in coils number one and two is fixed at 17 A, the current in coil number three is varied and that in coils number four to ten is fixed at 20 A. The V_0 is 55 KV. In the case of rising I_3 the power output is influenced by the variation in I_3 . It falls to very small values in the range of 16.5 to 23 A. This points to the possibility that once multipactor starts in cavity number one, it tends to

persist. For I_3 decreasing from 26 A the P_0 remains high down to 18 A, indicating a substantial hysteresis. There is a sharp resonance at the point 16.5 A for both rising and falling curves for I_3 . This is the region of cyclotron resonance.

Such a wide range of I_3 , at which the power goes down, was not however observed when current in all coils other than number 3 was fixed at 20 A and V_0 was 50 KV. This indicates that the phenomenon observed in Fig. 17 was probably due to cyclotron resonance in cavity number one as well as the gun region, as a current of 17 A in coils number one and two, would be conducive to such a resonance.

3.8 VARIATION OF PRESSURE IN THE TUBE AS A FUNCTION OF OPERATING PARAMETERS

Since one expects perturbations in the beam due to the phenomena which are being studied, it was considered desirable to observe the variations in pressure with variation of the focus current. This was made possible by the fact that the tube has a sputter-ion pump already sealed on, which also gives an indication of the pressure.

Figure 18 shows curves of power output as well as of pressure variations, as functions of focus current. The anode voltage was set at 50 KV and input drive power at 12 W. It is seen that for a rising value of I_{mag} , the changes in pressure follow fairly closely the changes in the power output up to 17 A. Beyond that, gasses released at the transition point at 17 A are progressively pumped out while the power output stays high.

By contrast, for the curve for decreasing value of I_{mag} the rise in pressure occurs at the region where the power level falls. Furthermore, rise in pressure occurs at a slightly lower value of I_{mag} (i.e., 16.6 A) than the fall in power (at 17.0 A). This indicates that the rise in pressure is an effect, and not a cause. The likely causes could be a change in the beam profile and its increased interception, or the start of a multipactor mode.

From the nature of the relationship between power output curve and the pressure variations one can deduce that the release in gasses on the upward curve of I_{mag} occurs in the output region, as the increased pressure coincides with increased power output, increased bunching and lateral defocusing. By the same argument, on the decreasing I_{mag} curve, the decrease in power output could be attributed to perturbing phenomena occurring in the earlier cavities, causing a decrease in bunching and a decrease of power output (accompanied by release of residual gases and increase of pressure).

Plotted in Fig. 19 are similar curves for power output as well as the pressure, with variation of focus current through coils number three to ten at an anode voltage of 80 KV and input power of 10 W. In this case the pressure variation generally follows the power output curve. There is also very little hysteresis. (This is indicative of the fact that at the higher voltages near the normal operating voltage there is less perturbation of the beam profile due to cyclotron resonance or multipactor).

Observations of pressure were also taken keeping the input value and focus current constant and varying the anode voltage. It was seen that the rise in pressure was sharply peaked at certain voltages. These were at 37, 40 and 43 KV.

3.9 FREQUENCY SPECTRA IN RF ENVELOPES

The spectra and rf envelopes were studied especially where transitions were taking place. A few representative types of behavior are shown in Figs. 20 and 21. In these figures a sequence is seen going from a clean spectral line to the appearance of additional side bands at the points of instability. These side bands as well as oscillations in the time domain increase with increased drive power. This ultimately leads to an unstable operation and relaxation oscillations.

4. Discussion of Results

The operation of a CW high power klystron has been studied as a function of the variation of focusing magnetic field along the axis over a wide range of parameters. The changes can be attributed to cyclotron resonance, and to the influence of magnetic field on multipactor phenomena.

It is seen that under certain conditions there can be a sharp drop in power output and a corresponding increase in the collector dissipation. The perturbations have a threshold of input drive power which tends to be very sharp. The threshold level of input drive can be attributed to attainment of a secondary emission coefficient higher than one in multipactor. The threshold value decreases with increase of anode voltage.

The changes near cyclotron resonance have sharply defined features, when the input drive level is close to the threshold. These are broadened out as the input drive level increases.

Regions of hysteresis are observed as between the behavior for a rising value of magnetizing current and a decreasing value of magnetizing current. These could be understood as follows: (a) start of different modes of multipactor at different values of magnetic field, the latter influencing their transit time, although once a given mode gets started it tends to be sustained; (b) the resonance occurs in different regions at different values of focusing current and is accompanied by some release of gases there, presumably due to defocusing effects of the electron beam or due to multipactor-ing electrons.

Some observations, where corresponding sharp transitions were measured for different values of anode voltage, indicate an increase in the required magnetizing current for the transition with increase in anode voltage. The ratio was in accord with the relativistic change of mass of electrons.

The magnetic field at the fourth and the fifth cavity and the output region passing through resonances has a less striking effect on the phenomena observed than if this happens in the region of the first three cavities or the gun region.

The effects of the second harmonic cavity can be correlated with similar effects observed by mechanical tuning. This is indicative of an electronic tuning due to space charge. When the cavity is initially detuned, the space charge tuning can result in either increase or decrease of power output, depending upon the direction of change from the optimum frequency.

The phenomena are fairly well reproduced from run to run. This is especially true of changes directly attributable to cyclotron resonance.

The variations of residual pressure in the tube as a function of the focus current correlate with variations of power output in two ways. One set of variations closely follows those of the power output for the case of a rising value of the focusing current. This indicates release of gases mainly in the output region. When the focusing current decreases, the changes in power output are in the opposite sense to the rise in pressure. This is indicative of resonances on the input side of the tube.

It would be worthwhile to carry out further experiments using multiple channel recorders which may simultaneously record changes in output power, rise in temperature in the cooling fluid in different sections, residual pressure and pickup from the cavities. These would help to further pinpoint the origin of the different changes as a function of variations in the magnetic field.

It would also be worthwhile to study the phenomena after coating the inner surfaces of the first three cavities and the drift tubes with very thin layers of titanium or titanium oxide so as to reduce secondary emission and tendency to multipactor. This would tend to reduce the Q of the cavities. However, the effect of that change would probably be less pronounced in the second harmonic cavity than in the case of the

first two cavities. The experiment could be first tried out on the second harmonic cavity. This, and a choice of magnetic field profile to stay away from resonances in the more sensitive areas, could raise the threshold drive power at which the klystrons could operate stably, and also raise the output power available.

5. Conclusion

It is seen that in addition to the ratio of the focusing field to the Brillouin field, an important parameter, which has a bearing on the operation of a high power klystron, is the ratio of the magnetic field to the one corresponding to cyclotron resonance. The effects are more pronounced when these resonances occur either in the gun region or in the first three cavities. In going to higher and higher powers, it would be important to keep these considerations in mind when choosing the profiles of magnetic fields in different regions of the klystron.

ACKNOWLEDGEMENTS

The valuable help rendered at various stages of preparation of the manuscript by Ms. Edythe Christianson, Mr. B. S. Gaira and Mr. Ishwar Singh, and in the preparation of drawings by Mr. P. S. Chopra and Mr. Y. N. Gupta, is thankfully acknowledged.

References

1. J. F. Gittins, "Power Travelling-Wave Tubes," (English Universities Press 1965), Chap. 4, pp. 86-114.
2. P. J. Tallerico, "Transverse Effects in the High Power Multicavity Klystron," *Proc. of the 8th Int. Conf. on Microwave and Optical Generation and Amplification, Amsterdam, Netherlands, 1970*, pp. 14-1 to 14-6.
3. T. Kageyama, Y. Morizumi and E. Watanabe, "A Large Signal Analysis of Broadband Klystrons with Design Applications," *Trans. IEEE, Vol. ED-24*, January 1977, pp. 98-100.
4. G. B. Collins, "Microwave Magnetrons," McGraw Hill Book Co., 1948, pp. 98-100.
5. M. P. Forrer *et al.*, "Duplexing and Switching with Multipactor Discharges," *Proc. I.R.E., April 1962*, p. 442.
6. G. T. Konrad, "Performance of a High Efficiency High Power UHF Klystron," presented at the Particle Accelerator Conference, Chicago, Illinois, March 16-18, 1977.
7. D. H. Priest and R. C. Talcott, "Heating of Output Windows of Microwave Tubes by Electron Bombardment," *Trans. I.R.E., ED-8*, 1961, p. 243.

Figure Captions

- Figure 1 Cross section of the PEP klystron.
- Figure 2 Magnetic field along the axis for a current of 20 A, flowing through the coils individually, and all together.
- Figure 3 Power output, and rise of temperature of cooling fluid in various sections of the klystron as a function of current through coils number three to ten (I_{mag}). $V_0 = 36$ KV, $I_0 = 4.81$ A, $P_{in} = 8.5$ W.
- Figure 4 Power output as a function of I_{mag} . A region of hysteresis is observed: $V_0 = 34$ KV and 38 KV, $P_{in} = 7.1$ W.
- Figure 5 Power output and pickup from second harmonic cavity as functions of I_{mag} . $V_0 = 38$ KV, $P_{in} = 8.4$ W.
- Figure 6 Performance of PEP-2 Klystron as a function of second harmonic cavity tuning ($V_0 = 38$ KV, $f_0 = 353.2$ MHz).
- Figure 7 Pickup from probes in cavities number one to four as functions of I_{mag} , $V_0 = 32$ KV, $P_{in} = 8.5$ W.
- Figure 8 Power output as a function of I_{mag} , with second harmonic cavity retuned to 696.508 MHz. V_0 at 34 KV, 36 KV and 38 KV, and $P_{in} = 8.5$ W.
- Figure 9 Power output as a function of I_{mag} , with second harmonic cavity retuned to 708.182 MHz. V_0 at 32 KV, 36 KV and 38 KV, and $P_{in} = 8.5$ W.

- Figure 10 Power output versus I_{mag} curves for different input drive power levels, indicating sharp threshold effects.
- Figure 11 Variation of threshold for input drive power level as function of anode voltage.
- Figure 12 Power output as a function of I_{mag} just at the input power threshold of instability. $V_0 = 45$ KV, $P_{in} = 5.7$ W.
- Figure 13 Two sets of curves of power output as a function of I_{mag} at threshold of input power as a check on reproducibility. V_0 at higher value of 57 KV, $P_{in} = 5.2$ W.
- Figure 14 Power output as a function of I_{mag} at higher values of input drive, viz., 10 W, 15 W, 20 W and 24 W. $V_0 = 45$ KV.
- Figure 15 Power output as a function of current in coils number seven to ten (towards output side). $V_0 = 50$ KV; current in coils number three to six is 20 A.
- Figure 16 Power output as a function of current in coils number four, five and six (near second harmonic cavity); current in coil number three is 15 A and that in coils number four to ten is 20 A.
- Figure 17 Power output as a function of current in coils number three (near input cavity). Current in coils number one and two is 17 A. Current in coils number four to ten is 20 A; $V_0 = 55$ KV.
- Figure 18 Comparison of power output and residual pressure as a function of I_{mag} (current in coils number three to ten); $V_0 = 50$ KV, $P_{in} = 12$ W.

Figure 19 Comparison of power output and residual pressure as functions of I_{mag} ; $V_0 = 60$ KV, $P_{in} = 10$ W.

Figure 20 Frequency spectra and rf envelopes near instability points.
 $V_0 = 40$ KV.

- (a) $I_{mag} = 16.4$ A and $P_{in} = 8.5$ W (frequency spectrum).
- (b) $I_{mag} = 16.5$ A and $P_{in} = 20$ W (frequency spectrum).
- (c) $I_{mag} = 16.5$ A and $P_{in} = 20$ W (rf envelope).
- (d) $I_{mag} = 17.7$ A and $P_{in} = 20$ W (frequency spectrum).
- (e) $I_{mag} = 17.7$ A and $P_{in} = 20$ W (rf envelope).

Figure 21 (a) Frequency spectrum for $I_{mag} = 22.6$ A; $P_{in} = 24$ W.
(b) rf envelope for $I_{mag} = 22.6$ A; $P_{in} = 24$ W.
(c) A repeat of (b) at a little later time.
(d) Relaxation oscillation shown in rf envelope for
 $I_{mag} = 16.5$ A; $P_{in} = 24$ W.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Fig. 18

Fig. 19

(a)

(b)

(c)

(d)

(e)

3-84
4761A20

Fig. 20

(a)

(b)

(c)

(d)

3-84

7751A21

Fig. 21