

5.3 Performance of the controlled C.V.T. with load variation

Fig. 5.4 shows the variation of the output voltage as a function of load current. The two bands of operation illustrate the output voltage of the C.V.T. at no-load and at full-load respectively. The output voltage at no-load lies between 219,5 V and 220,5 V whilst at full-load the output voltage lies between 220,5 V and 221 V.

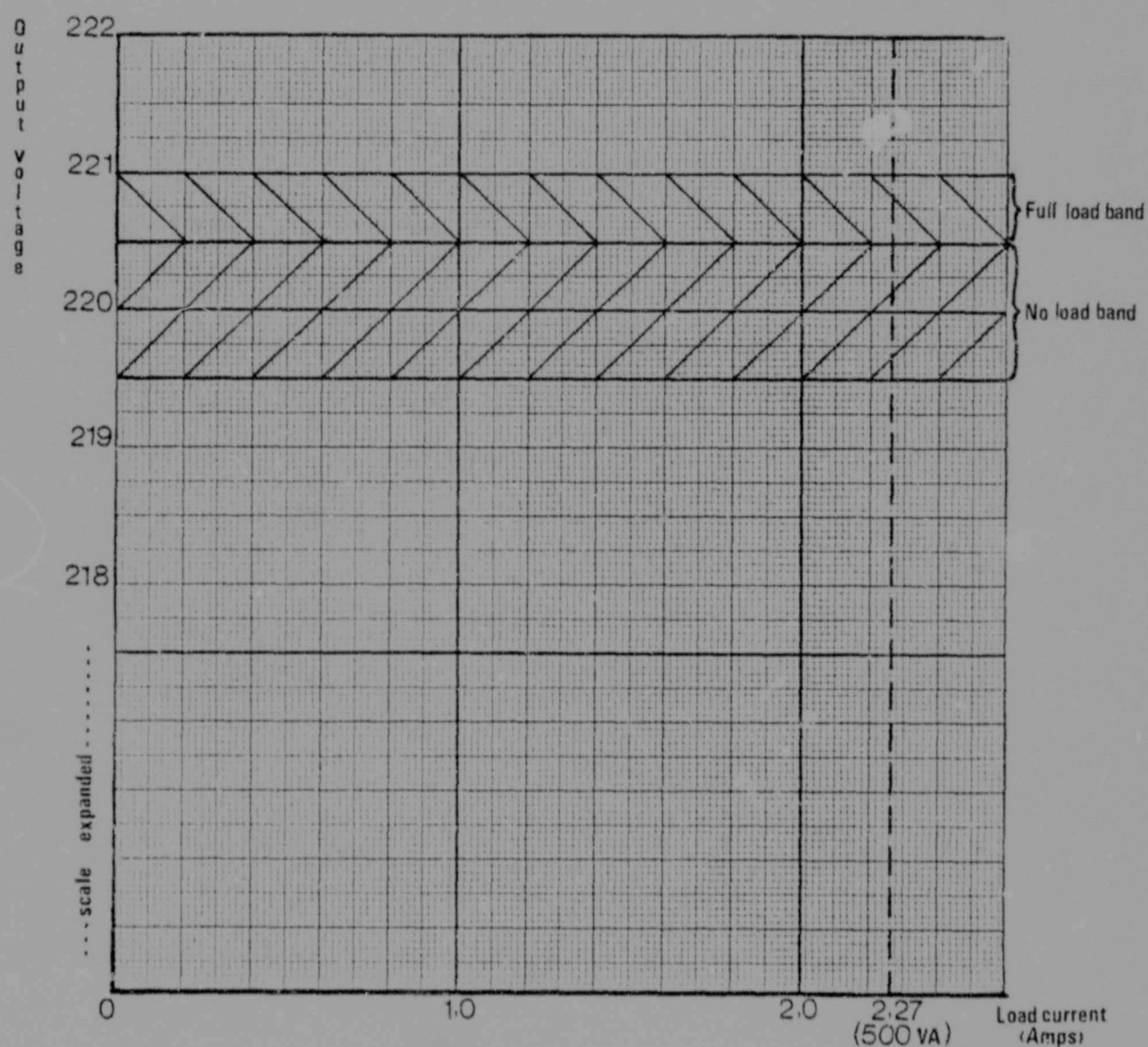


Figure 5.4 Output voltage versus load current showing the two bands of operation for the 48 to 52 Hz frequency range and the -20% to + 10% input voltage variation.

5.4 Current limiting curves

The output voltage of the controlled system is measured against the load current to establish the current limiting capability of the device. The additional windings required for the saturable reactor circuit increase the impedance of the device and thus decrease the short circuit current.

Figs. 5.5 a, b and c are the current limiting curves for different input voltages. The current limit curves for the uncontrolled device are given by Figs. 5.6 a, b and c. The short circuit current is less for the controlled device at each frequency and input voltage. For example the short circuit currents at $V_{in} = 220 \text{ V}$, 50 Hz for the controlled and uncontrolled devices are $\frac{3.98}{2.27} = 1.753$ and $\frac{4.56}{2.27} = 2.009$ times full-load current respectively.

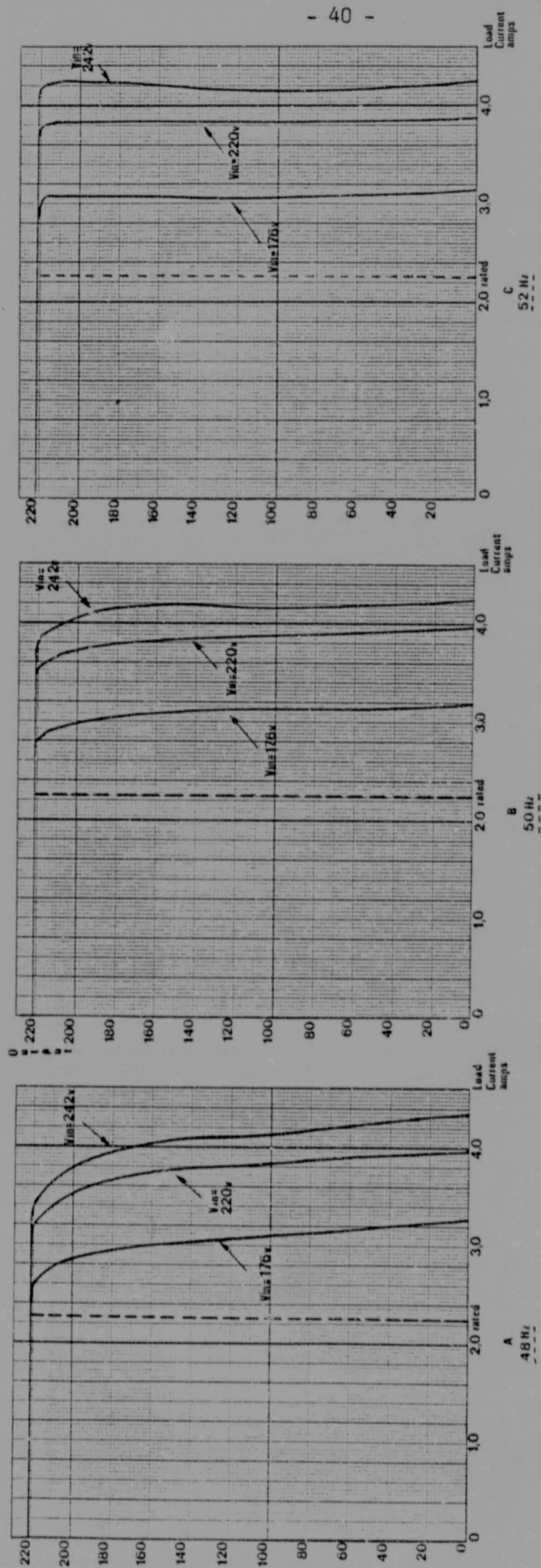


Figure 5.5 Current limit curves for a range of input voltages at different frequencies (WITH FEEDBACK CONTROL)

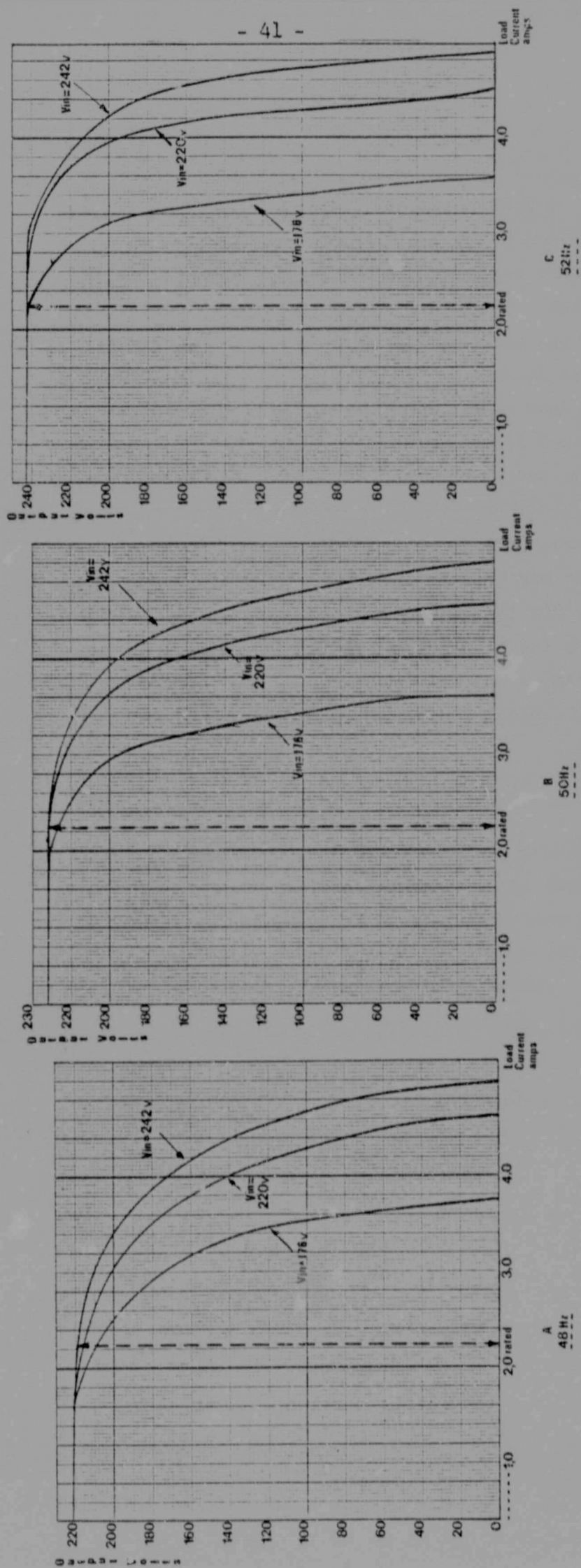


Figure 5.6 Current limit curves for a range of input voltages at different frequencies (WITHOUT FEEDBACK CONTROL)

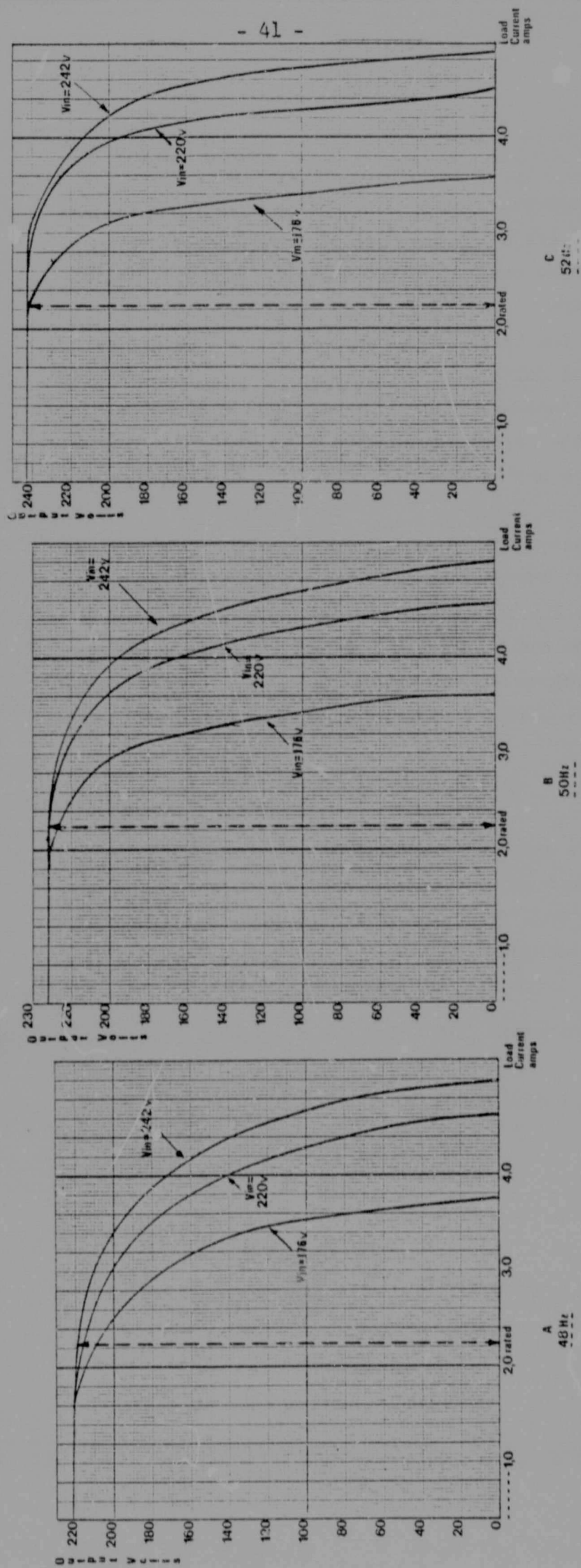


Figure 5.6 Current limit curves for a range of input voltages at different frequencies (WITHOUT FEEDBACK CONTROL)

5.5 Harmonic Distortion

Photographs of the output voltage waveform and its spectrum are shown at no-load and full-load for 48, 50 and 52 Hz respectively. The proposed specification calls for less than 3,5% total harmonic distortion for all full-load conditions. Table 2 shows that at 220 Volts, 50 Hz, full-load, the uncontrolled and controlled units exhibit a similar harmonic distortion which is slightly above the specification. Also, it has been stated that opening the gap of the C-core C_3 of Fig. 2.3 or of the split C-core C_3 and C_3' in Fig. 3.1 improves the distortion but worsens the stability.

Figs. 5.7 to 5.12 are photographs of the output voltage waveshapes and their respective spectra at no-load and full-load, for different frequencies and with an input voltage of 220 volts (See Note 1). Only photographs of the controlled unit are shown. The distortion of the output voltage waveshape for the uncontrolled device has been calculated and given in Table 2 (Chap. 3).

Note:

1. In the spectrum analyser results shown, the dB values are read from the "0 dB" line (i.e. top graticule line) down in units of -10 dB/div. The base value represented by the "0 dB" line is shown for every trace. For the horizontal axis, the measuring bandwidth in Hz is given together with the frequency scale in Hz/div.
i.e. (base dB value, scale units/div, measuring bandwidth, Hz/div).
2. On the vertical scale 0 dB corresponds with 1,0V.

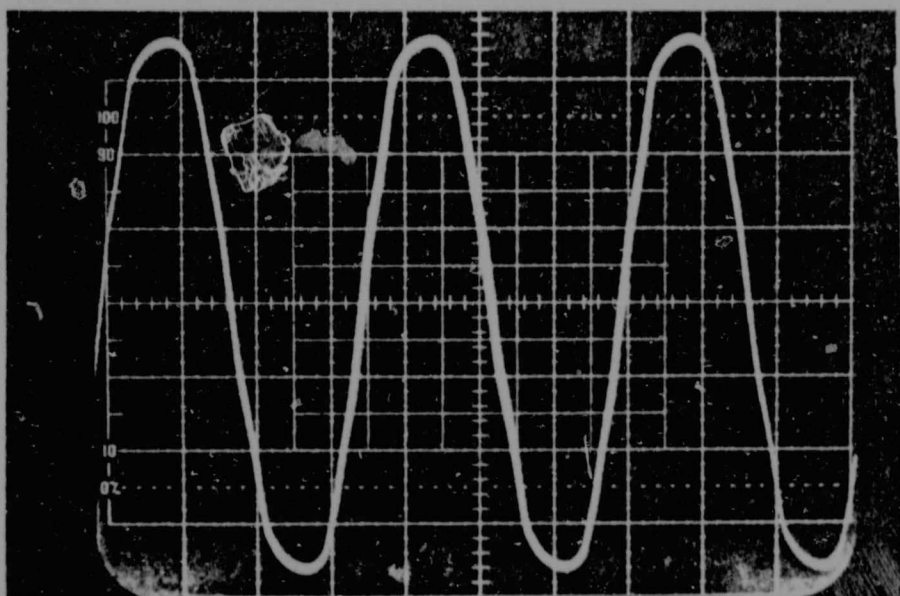
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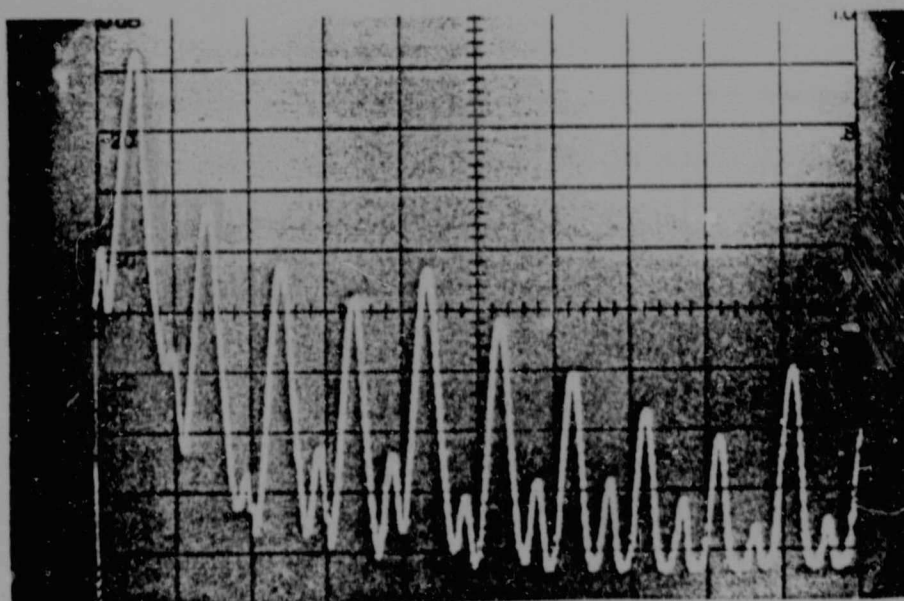
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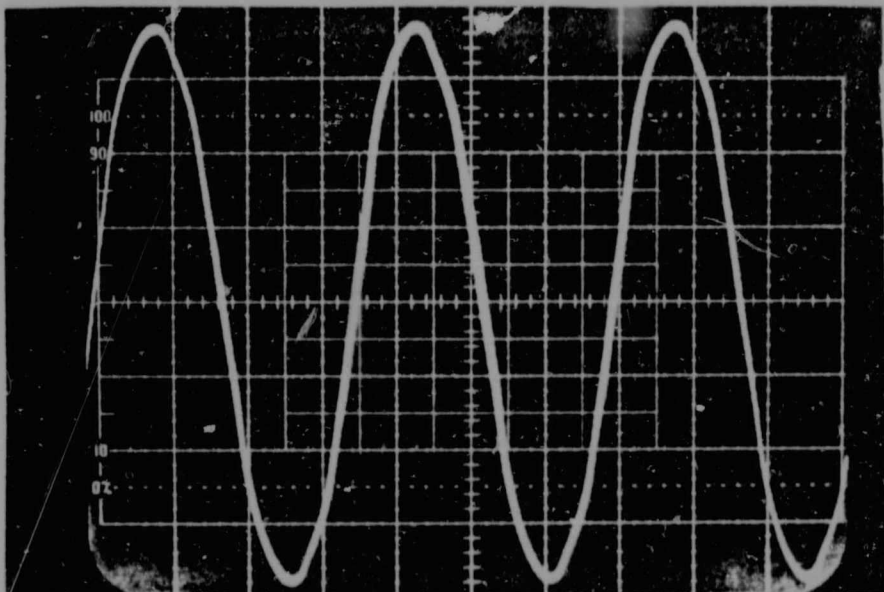
86 V/div
6 msec/div



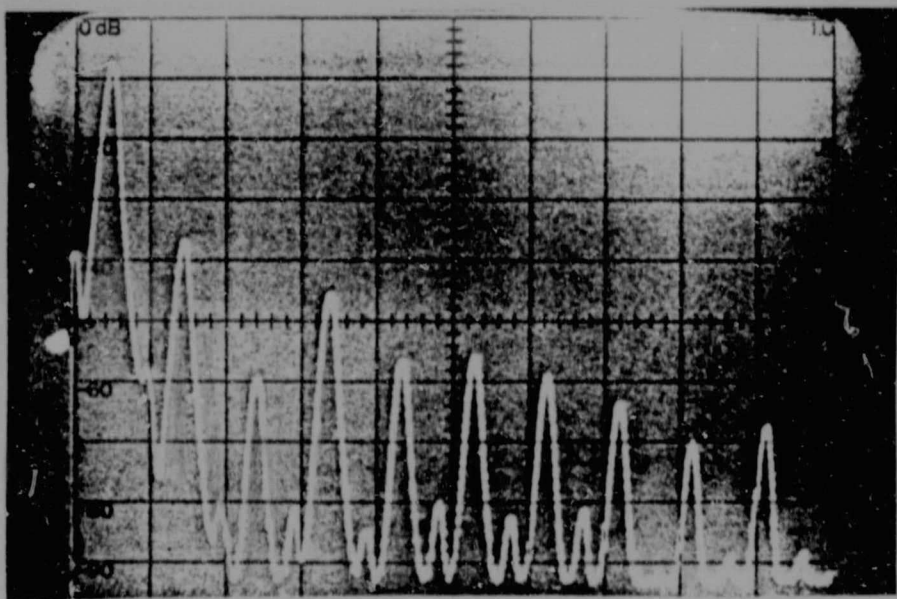
No-load (48Hz)
Vin = 220 V
Vo = 220 V
% Distortion = 5.02%

(+ 54 dB, 10 Hz BW, 100 Hz/div)

Figure 5.7 Waveshape of output voltage waveform and its spectrum
for the controlled C.V.T. (No-load, 48 Hz condition)



86 v/div
6 msec/div

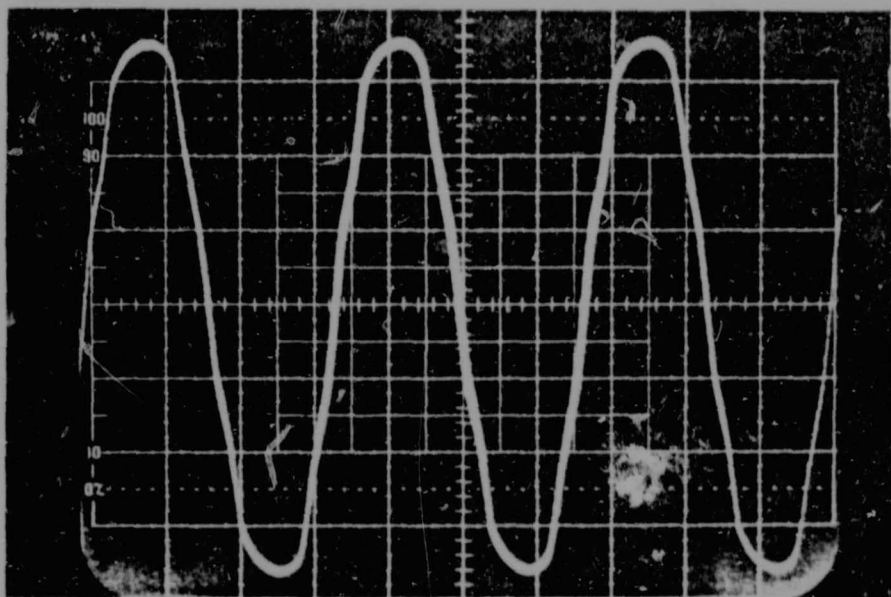


Full-load (48 Hz)

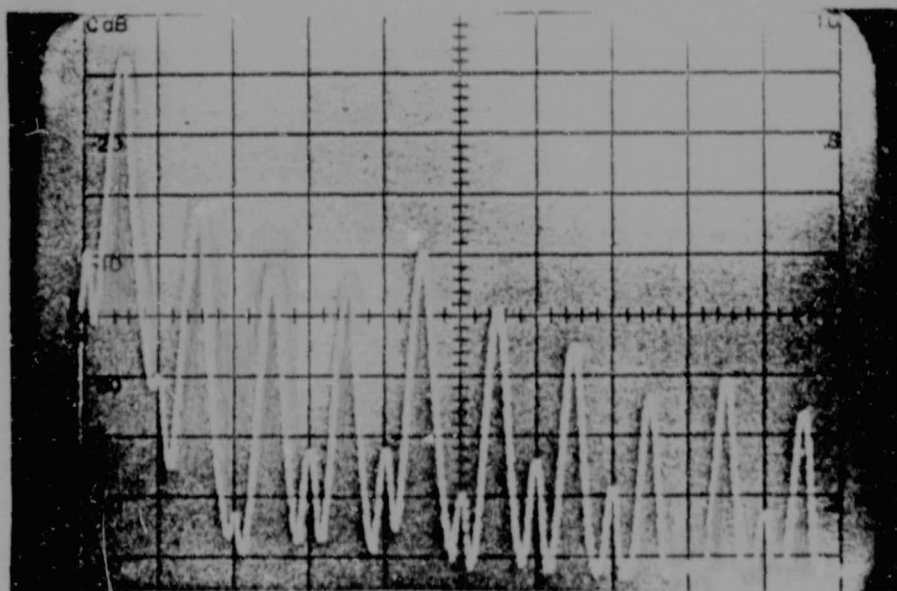
$V_{in} = 220 \text{ V}$
 $V_{out} = 220 \text{ V}$
% Distortion = 3.42%

(+54 dB, 10 Hz BW, 100 Hz/div)

Figure 5.8 Waveshape of output voltage waveform and its spectrum for the controlled C.V.T. (Full-load, 48 Hz condition)



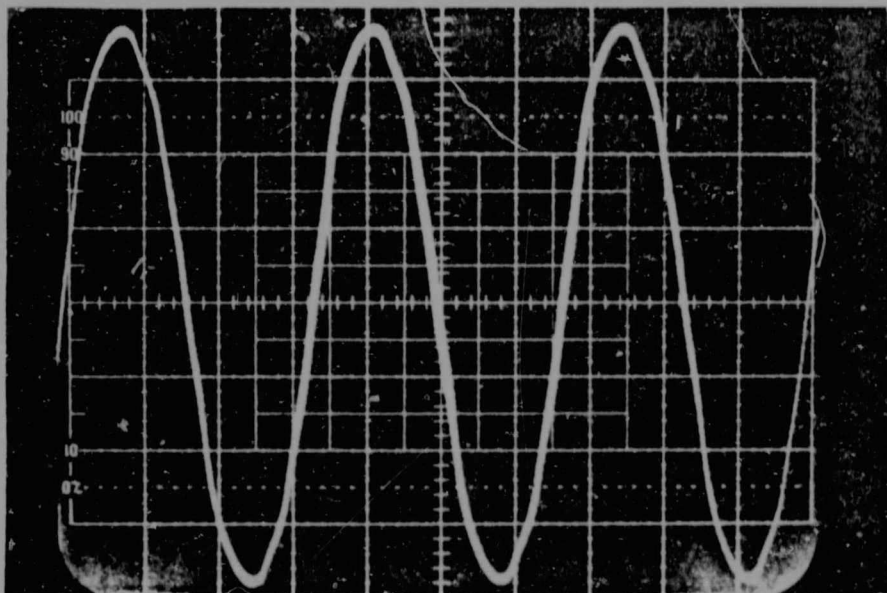
86 V/div
6 msec/div



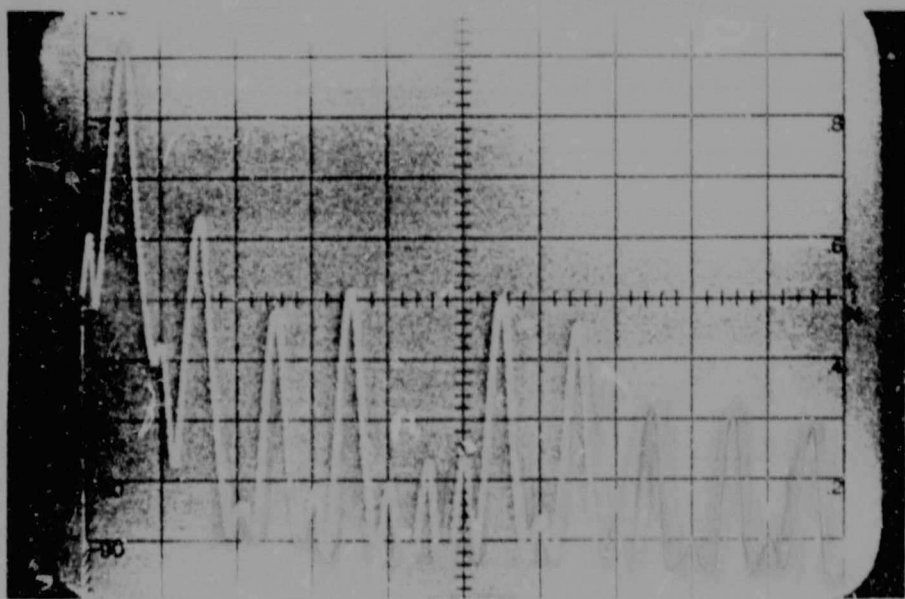
No-load (50 Hz)
 $V_{in} = 220 \text{ V}$
 $V_o = 219,5 \text{ V}$
% Distortion = 5,06%

(+ 54 dB, 10 Hz BW, 100 Hz/div.)

Figure 5,9 Waveshape of output voltage waveform and its spectrum for the controlled C.V.T. (No-load, 50 Hz condition)



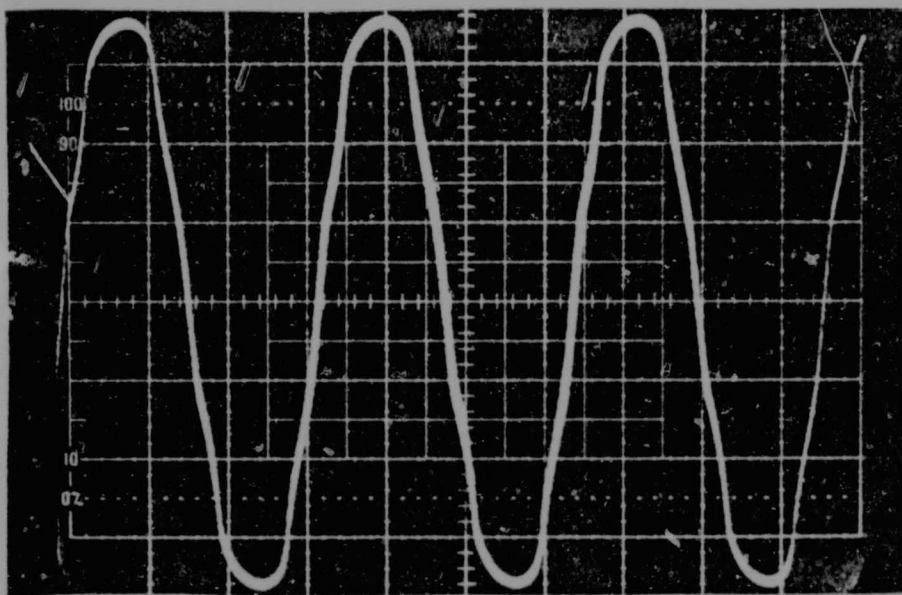
86 V/div
6 msec/div



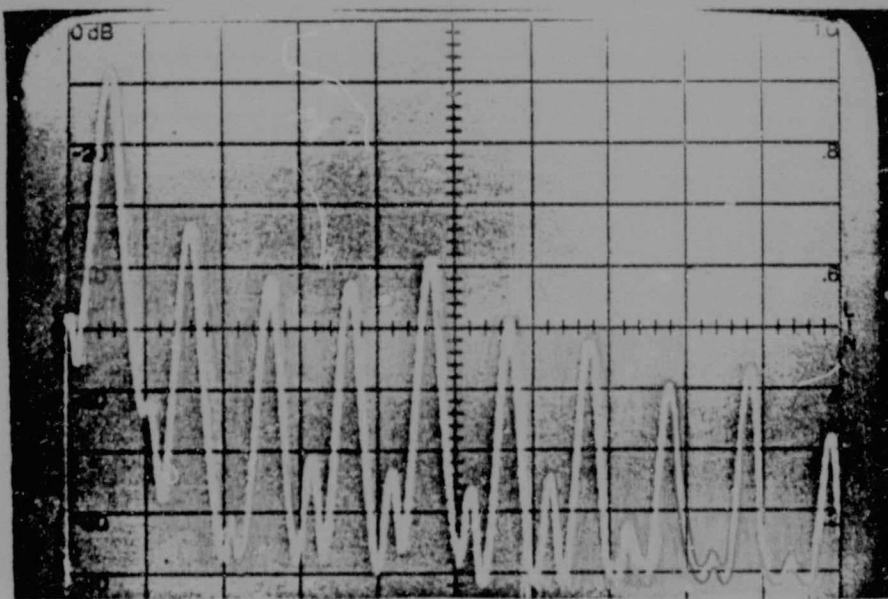
Full-load (50 Hz)
Vin = 220 V
Vout = 220,5 V
% Distortion = 3,07%

(+54 dB, 10 Hz BW, 100 Hz/div.)

Figure 5.10 Waveshape of output voltage waveform and its spectrum for the controlled C.V.T. (Full-load, 50 Hz condition)



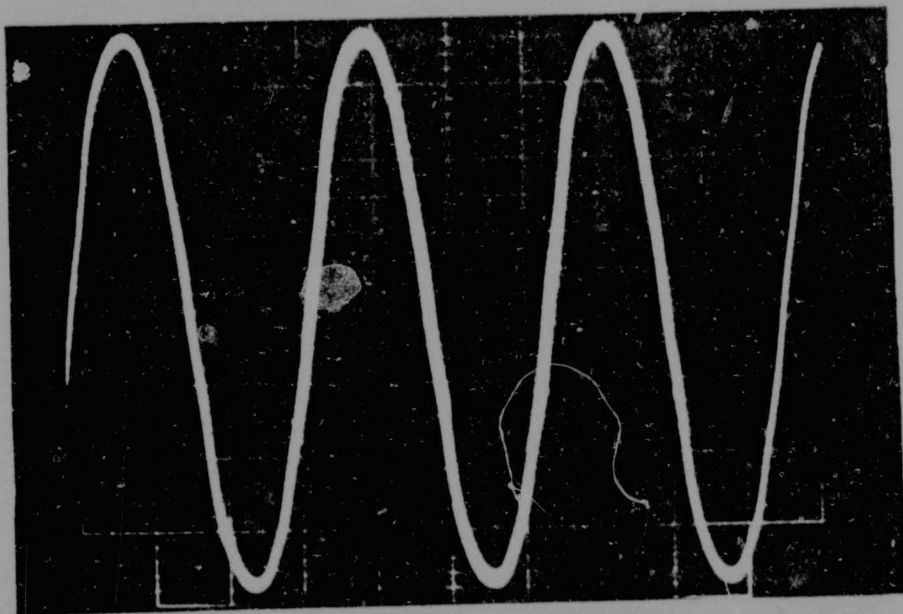
86 V/div
6 msec/div



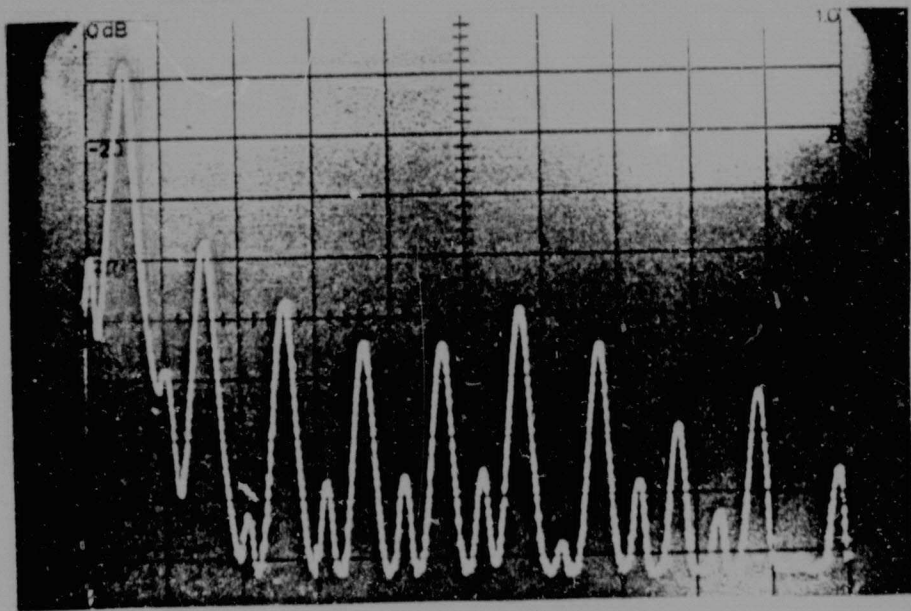
No-load (52 Hz)
Vin = 220 V
Vout = 219,5
% Distortion = 5,77%

(+ 54 dB, 10 Hz BW, 100 Hz/div.)

Figure 5.11 Waveshape of output voltage waveform and its spectrum for the controlled C.V.T. (No-load, 52 Hz condition)



86 V/div
6 msec/div



Full-load (52 Hz)
 $V_{in} = 220 \text{ V}$
 $V_{out} = 220,5 \text{ V}$
% Distortion = 3,15%

(+ 54 dB, 10 Hz BW, 100 Hz/div.)

Figure 5.12 Waveshape of output voltage waveform and its spectrum for the controlled C.V.I. (Full-load, 52 Hz condition)

Table 4 shows that the best case exists at $V_{in} = -25\%$, 48 Hz on full-load where the THD is 2,07%. The worst case is at $V_{in} = +15\%$, 48 Hz on no-load where the THD is 6,37%. These results prove that the C.V.T. can operate over a greater range of input voltages and still lie within the proposed specifications.

TABLE 4 Harmonic distortion at worst and best case

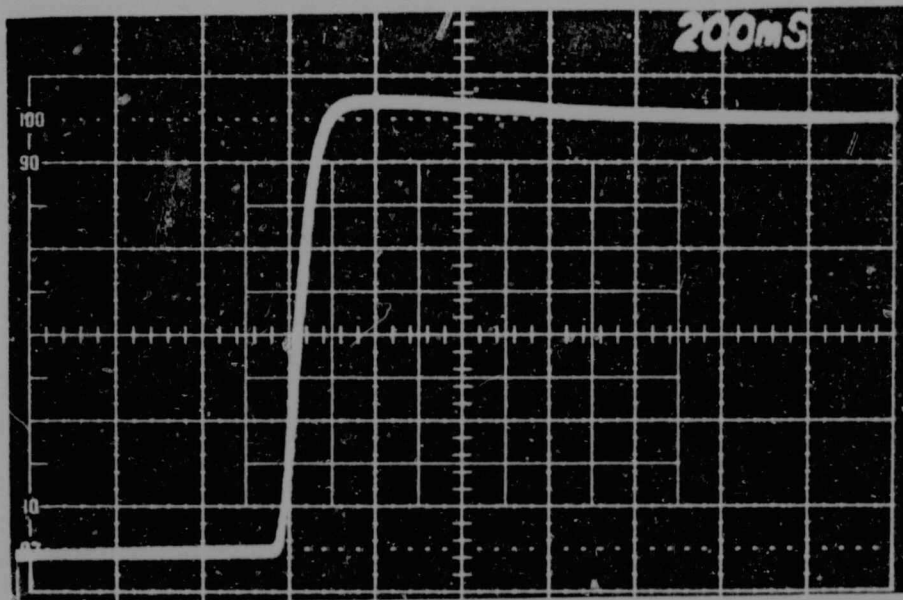
Percent Input Voltage	Input Voltage	Frequency (Hz)				
		48	52	48	52	
		No Load		Full Load		
Nominal = 220 Volts						
-25	165	5,50	5,15	2,07	2,95	%
-20	176	5,52	5,28	2,11	2,98	THD
+10	242	6,03	5,69	3,96	3,26	
+15	253	6,37	6,00	4,12	3,67	

5.6 System Response

The time taken from "throwing the switch" which supplies power to the controlled C.V.T. to the settling of the output voltage, is affected by two time constants. The first is the inherent time constant of the C.V.T. itself and the second is the delay before the control circuit acts to stabilise the output voltage.

The method used to capture the response time on the storage oscilloscope is now described. The spectrum analyser is pre-set at a frequency of 50 Hz. The spectrum analyser is also tuned to give a dc signal which is directly proportional to the ac RMS output voltage of the C.V.T. If the mains frequency is stable at the pre-set point and the output voltage remains constant, then the trace seen on the analyser screen is a straight line. The signal is now fed into the storage oscilloscope. Here the trace is the dc signal proportional to the C.V.T.'s RMS output voltage versus time. A slow time scale setting allows the user to track the signal from switch on until the output voltage reaches a constant value. As the switch is thrown the voltage rises and the overshoot is visible due to the output voltage not remaining constant. When the control circuit stabilises, the output voltage is seen as a straight line across the screen.

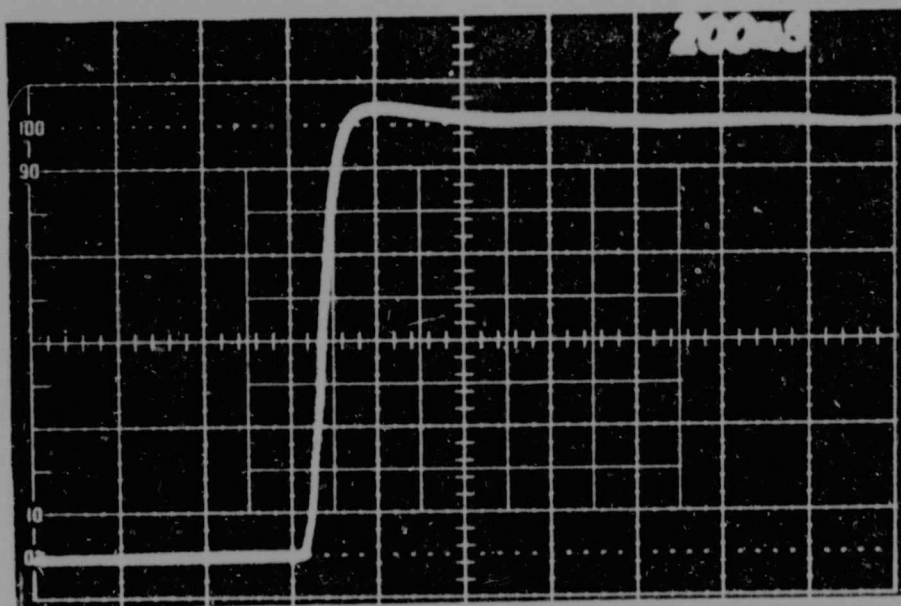
The following photographs have all been taken with an input voltage of 220V at 50 Hz. The trace covers 200 msec/div which is 10 full cycles/div of a 50 Hz sine wave. The oscilloscope is calibrated to show 0 and 220 Volts on the bottom and top dotted lines respectively. (See Figs.5.13 to 5.15). The overshoot is calculated as a percentage of the nominal steady state output voltage.



No-load (48 Hz)

% maximum overshoot = 4%
Settling time = 22,08 cycles

200 msec/div.

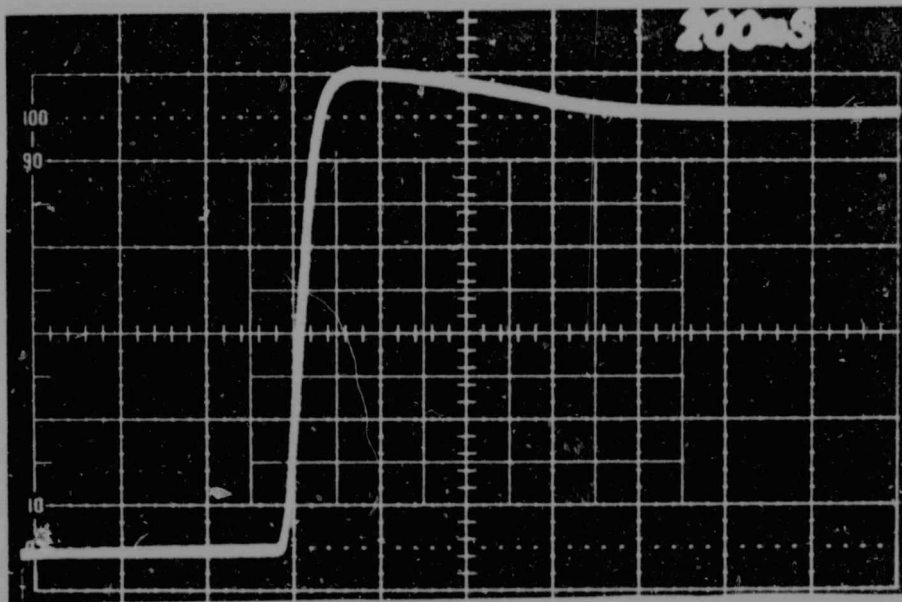


Full-load (48 Hz)

% maximum overshoot = 4%
Settling time = 9,6 cycles

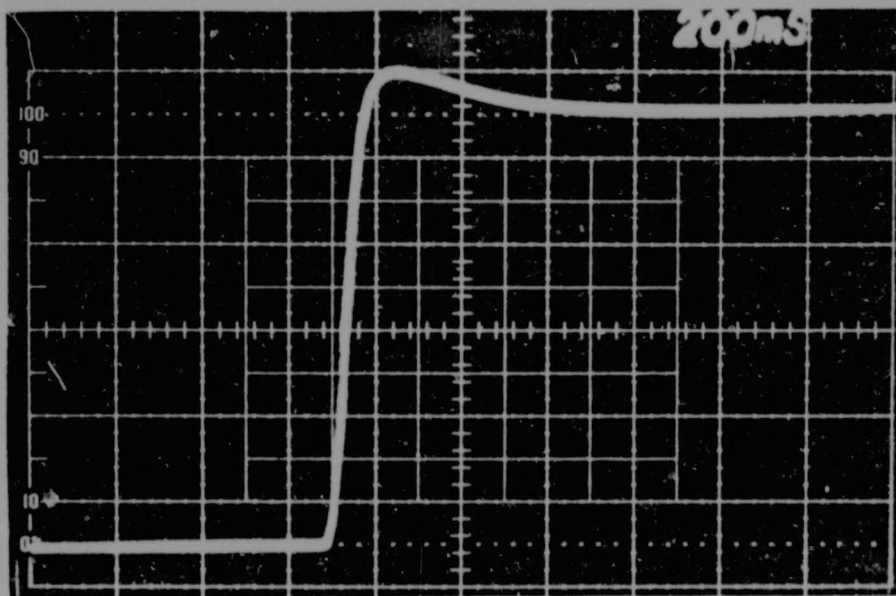
200 msec/div.

Figure 5.13 Response of controlled C.V.T. after switch on
(48 Hz condition)



No-load (50 Hz)
% maximum overshoot = 9%
Settling time = 29 cycles

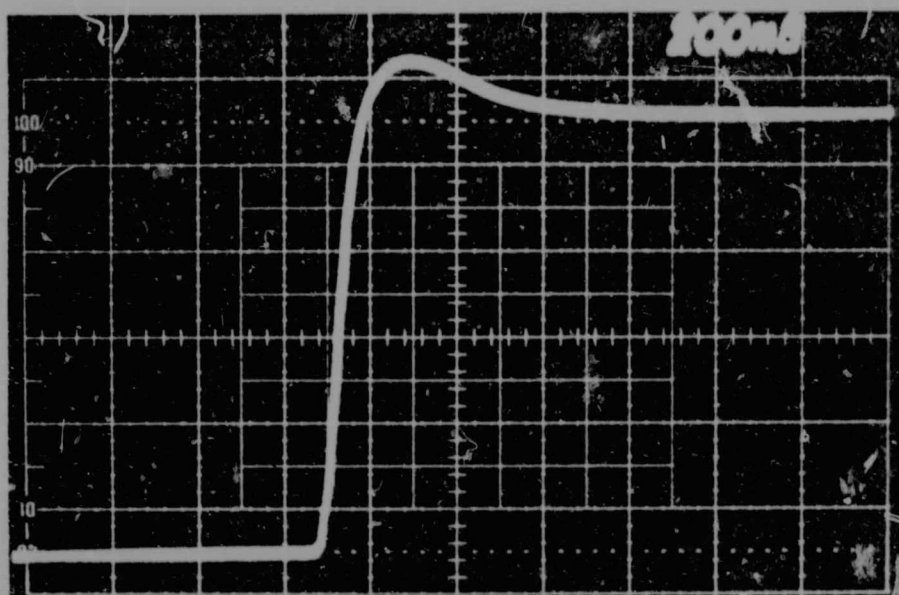
200 msec/div.



Full-load (50 Hz)
% maximum overshoot = 9%
Settling time = 18 cycles

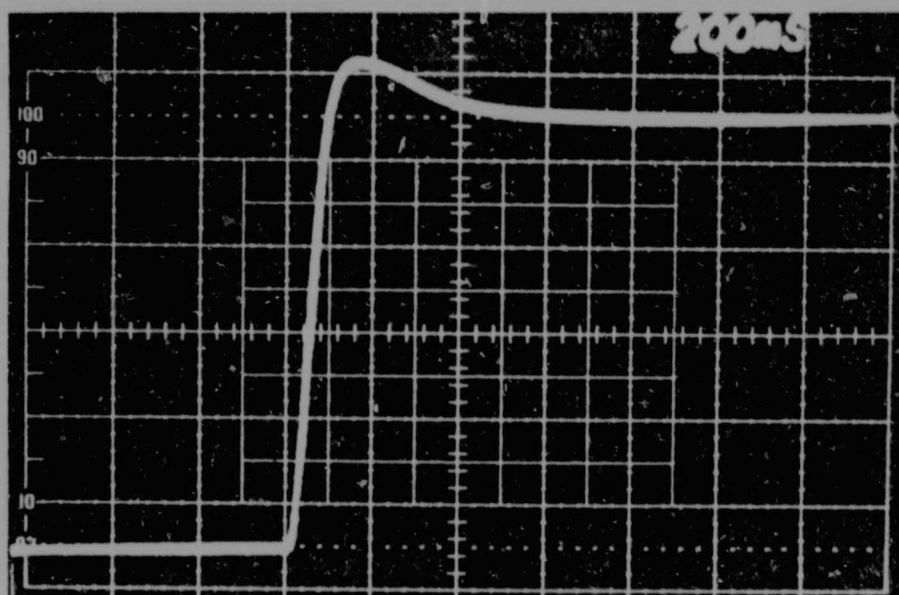
200 msec/div.

Figure 5.14 Response of controlled C.V.T. after switch on
(50 Hz condition)



No-load (52 Hz)
% maximum overshoot = 14%
Settling time = 26 cycles

200 msec/div.



Full-load (52 Hz)
% maximum overshoot = 12%
Settling time = 17.00 cycles

200 msec/div.

Figure 5.15 Response of controlled C.V.T. after switch on
(52 Hz condition)

From Figs.5.13 to 5.15 it is seen that the % overshoot increases as the frequency increases. This is expected due to the increase in output voltage. At 48 Hz, full-load (Fig. 5.13) a slight oscillation is evident. For this condition the lowest dc current is required (Table 1) and the error signal into the integrator (Fig. 4.8) is very small. The small ripple on the error signal is amplified by the integrator and passes through the voltage to current converter. The dc injection current therefore takes a few cycles to stabilise the output voltage.

On no-load there is no secondary leakage reactance volt drop which results in a higher output voltage than at full-load. Consequently the settling time is longer for no-load conditions. Table 5 gives the capacitor current for different input conditions.

TABLE 5 Capacitor current at different frequencies with an input voltage of 220 Volts.

Vin volts	Freq Hz	Capacitor current	
		Amps	
		No-load	Full-load
220	48	2,25	2,05
220	50	2,34	2,15
220	52	2,43	2,25

5.7 Increasing the range of operation

Measurements of the output voltage are provided at input voltages of -25% and +15% of rated value, and at frequencies of -6% and +6% of 50 Hz. It is stated in section 3.2 that a wider range of operation is possible with the selected operating point of the dc injection current. Table 6 shows the output voltages for these conditions.

TABLE 6 Output voltage at input voltages at -25% and +15% of rated voltage (220 Volts) and from -6% to +6% of rated frequency (50 Hz) on no-load and full-load.

		Frequency (Hz)							
Percent input voltage	Input voltage	47	48	49	50	51	52	53	
		OUTPUT VOLTAGE Vout							
- 25	163	221,0	220,0	220,0	220,0	220,0	220,5	220,0	NO
+ 15	253	220,5	219,0	219,0	219,5	219,0	219,5	219,0	LOAD
- 25	163	222,0	221,0	220,5	220,5	220,5	220,5	220,0	FULL
+ 15	253	221,0	219,0	220,5	220,5	220,5	220,5	220,0	LOAD

Thus, it is possible to improve the overall system performance. The stability under all these conditions is $\pm \frac{1}{220} \times 100 = \pm 0,45\%$

5.8 Summary of results

It is possible to increase the range of operation of the C.V.T. using the feedback arrangement described in Chap. 4. The stability of the device is very good and the total harmonic distortion is still within acceptable limits. The controlled device now satisfies most users' specifications in the power supply field (21).

CHAPTER 6

CONCLUSION

The main objective of this research project was to prove that the output voltage of a C.V.T. could be controlled when the mains frequency varies. The fact that this objective was achieved is very clearly demonstrated in Chapters 3 and 5. In these chapters it may be seen that the stability of the C.V.T. is greatly improved with the use of a simple continuous control system. The output voltage remains constant within $\pm 1\%$ for variations in frequency of $\pm 4\%$ about 50 Hz and changes in input voltage from -20% to +10% around 220 Volts. All components used in the simple circuit are easily available and cheap. The circuit design procedure is simple. No external power supplies are necessary to supply the circuitry. Improvements can be made to the circuit which could then compensate for temperature rise by using more expensive components. The stability could be improved to $\pm 0.1\%$ by adding additional filter stages which eliminates any ripple.

The user can upgrade the circuit to control larger KVA rating C.V.T.'s by simply increasing the dc current gain in the transistor amplifier. The output voltage may be set at a desired point by simply adjusting a potentiometer. There is no necessity to adjust the gaps in the C-cores to alter the output voltage.

The disadvantages of this design include a lower efficiency, extra costs due to additional circuitry and materials, a slow response time and restricted limits of operation. However, measurements taken for a wider range of input voltages and frequencies prove that the device operates satisfactorily under more stringent conditions than those specified.

The original proposal was for a stable dc power supply. However, due to efficient third harmonic voltage compensation and filtering as well as the arrangement of the saturable reactor winding, an acceptable ac output waveform was achieved. Most computers and electronic equipment require ac power from the mains and therefore the decision was taken to concentrate on the ac performance of the device.

It has been proved that the output voltage of the constant voltage transformer can be controlled when the mains frequency changes. As more people and organisations become aware of the importance of a stable ac supply, the advantages of the C.V.T. places it in a secure position as a reliable and cheap supply which complies with most electrical specifications.

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Author Cohan H E

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