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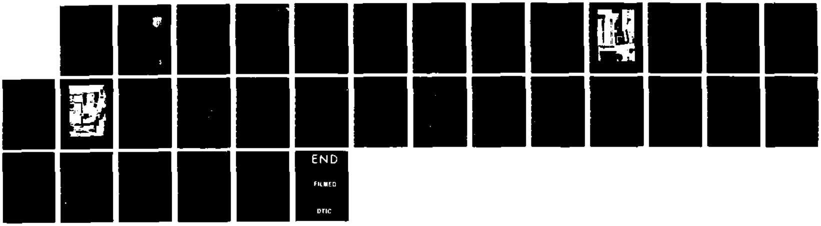

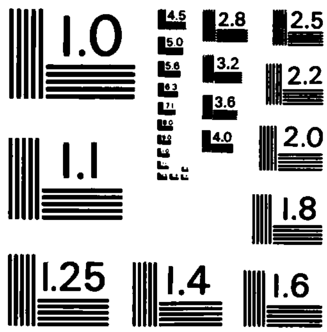

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Volume IV

DIGITAL SERVOCONTROLLER SYSTEM
Volume IV - Results and Conclusions

Jorge Lopez
Kevin Miller

Southwest Research Institute
San Antonio, Texas

February 1985

Final Report for Period July 1983 - November 1984

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This final report describes an exploratory development effort for the design and fabrication of a digital servocontroller system for load control in full-scale air-frame fatigue tests. Each digital controller replaces four analog controllers. The LSI-11/23 microcomputer in the digital controller executes a PI algarithm to implement direct digital control. It may operate in a stand-alone mode or as a slave processor to a master computer via fiber optic link. Other programmable features specifying loop parameters, building load profiles, adjusting control system gains and monitoring alarm and abort conditions.

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PREFACE

This is the final report of work accomplished and results achieved at the Experimental Control Group, Structures Test Branch, AFWAL/FIBT, WPAFB, Ohio. The digital servocontroller was developed by Southwest Research Institute, San Antonio, Texas, under Contract F33615-83-C-3201 during the time period July 83 thru November 84.

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1.0 INTRODUCTION

This document details the results of Southwest Research Institute's (SwRI) development of a prototype servocontroller system for the Air Force Wright Aeronautical Laboratories (AFWAL) under Contract No. F33615-83-3201. The system which has been developed is a multichannel digital servocontroller for use in the fatigue testing of airframes. It is shown in Figure 1. The servocontroller is a self-contained unit capable of controlling test loads which are applied to an airframe under test. An operator interface which presents the operator with real-time measurements of the critical control parameters for each channel is provided. The servocontroller is designed to be configurable to different load applications. A fiber optic communications link is in place which allows load profiles to be downloaded from a master computer to the servocontroller. Additional features which facilitate the start-up procedures (e.g., open loop bumping of individual channels for mechanical linking of the structure to the hydraulic struts and step or pulsed outputs to individual channels to aid in the tuning of the control loops) have been designed into the system. The system's stand-alone capabilities (profile generation and execution), versatility and easy operator interface make it well suited to applications which require few control channels.

Section 2 is a summary of the installation and checkout procedures. The hardware modifications which were required during this period are discussed. Section 3 highlights the features of the servocontroller system including versatility, speed and user friendliness. Section 4 discusses the limitations of the system. Test data which demonstrate the capabilities of the servocontroller system are provided in Section 5. Section 6 concludes this document with a summary of the program results and recommendations for continued efforts in this area.

FIGURE 1. DIGITAL SERVOCONTROLLER SYSTEM

2.0 SUMMARY OF INSTALLATION AND CHECKOUT PROCEDURES

The system was delivered in a disk-based configuration, that is, the system had not been "burned" into erasable programmable read only memory (EPROM). There were several reasons for this: 1) some software remained to be debugged; 2) certain software had not been completely tested (i.e., master computer download routines, self-tuning routines); and 3) it was anticipated that software modifications would be required in software that had been tested and debugged. It was jointly decided between SwRI and AFWAL personnel that the servocontroller features could be demonstrated using the disk-based system. Due to the ongoing software debugging, it was necessary to deviate from the planned verification of the system as discrete components. The interface between the hydraulic system and the servocontroller was easily accomplished. Digital control of the hydraulic servovalves was achieved within the first few days after delivery. The balance of the two-week installation and checkout period was dedicated to the verification and fine tuning of the servocontroller system. Sections 3 and 4 describe the results of the system verification in terms of the features and limitations of the servocontroller system.

There were two hardware modifications made to the servocontroller system. A cooling fan was added above the microcomputer card cage due to the temperature environment on the test floor. The environmental temperature did not allow for adequate heat dissipation. The second modification was the addition of a multifunction module to the microcomputer identical to the one which was originally installed into the system. One of the original intents of the system was to execute the system program directly out of EPROM. However, the method used in burning the program onto the EPROMs did not allow for this. Consequently, the system required that the program be loaded to random access memory (RAM) prior to execution. The multifunction module provides the required RAM (32 Kb) for this task. The multifunction card was selected over a dedicated RAM card in order to provide spare serial ports for the system in the event of failure.

3.0 SYSTEM FEATURES

The following is a list of the important operating features installed in the servocontroller system. Details on each feature can be found in the Operator's Manual - Final Report, Volume I.

- Up to four channels of control provided
- Two system modes: stand-alone operation and master-slave configuration
- Two loop modes of operation: open and closed
- Four function modes: ramp generation, haversine generation, step generation and operator-defined function generation
- Programmable ramp rates and ramp breaks
- Programmable dump rate
- Variable loop time, 2 to 10 ms
- Synchronization of channels in achieving different load levels
- Two methods for determining ramp time between levels: ramp-rate based and constant-time based
- Three hold options: constant time, percent of error and percent of ramp time
- Three abort options: dump, hold and lockup
- Real-time display of loop variables
- Three methods of load profile entry: download from master computer, operator manual entry and random generation
- Manual control of servocontroller gains
- Fiber-optic link between a host PDP-11 minicomputer and the servocontroller system

4.0 SYSTEM LIMITATIONS

This section's intent is to recognize the limitations of the servocontroller system. An objective of the system which was not realized was the self-tuning feature. The method for self tuning which was implemented did not operate as expected on the test stand. The reasons for this failure are not clear but may be traced to three sources: 1) the self-tuning algorithm chosen may not have been the proper one for the applicaton; 2) the self-tuning algorithm may not have been implemented properly; and 3) the system model used for the self-tuning algorithm may have been too simplistic. The constraints of time and money did not allow for a thorough investigation of the problem.

The servocontroller system as designed presently cannot be used as a "dumb" controller. That is, it cannot accept external analog commands but operates on internally generated setpoints based on the profile which has been entered.

The hold option operates such that a hold will occur only as a discrete load level. Therefore, if a hold is initiated while the controller is on a ramp to a certain load level, the ramp will be completed and the hold will occur at the programmed load level.

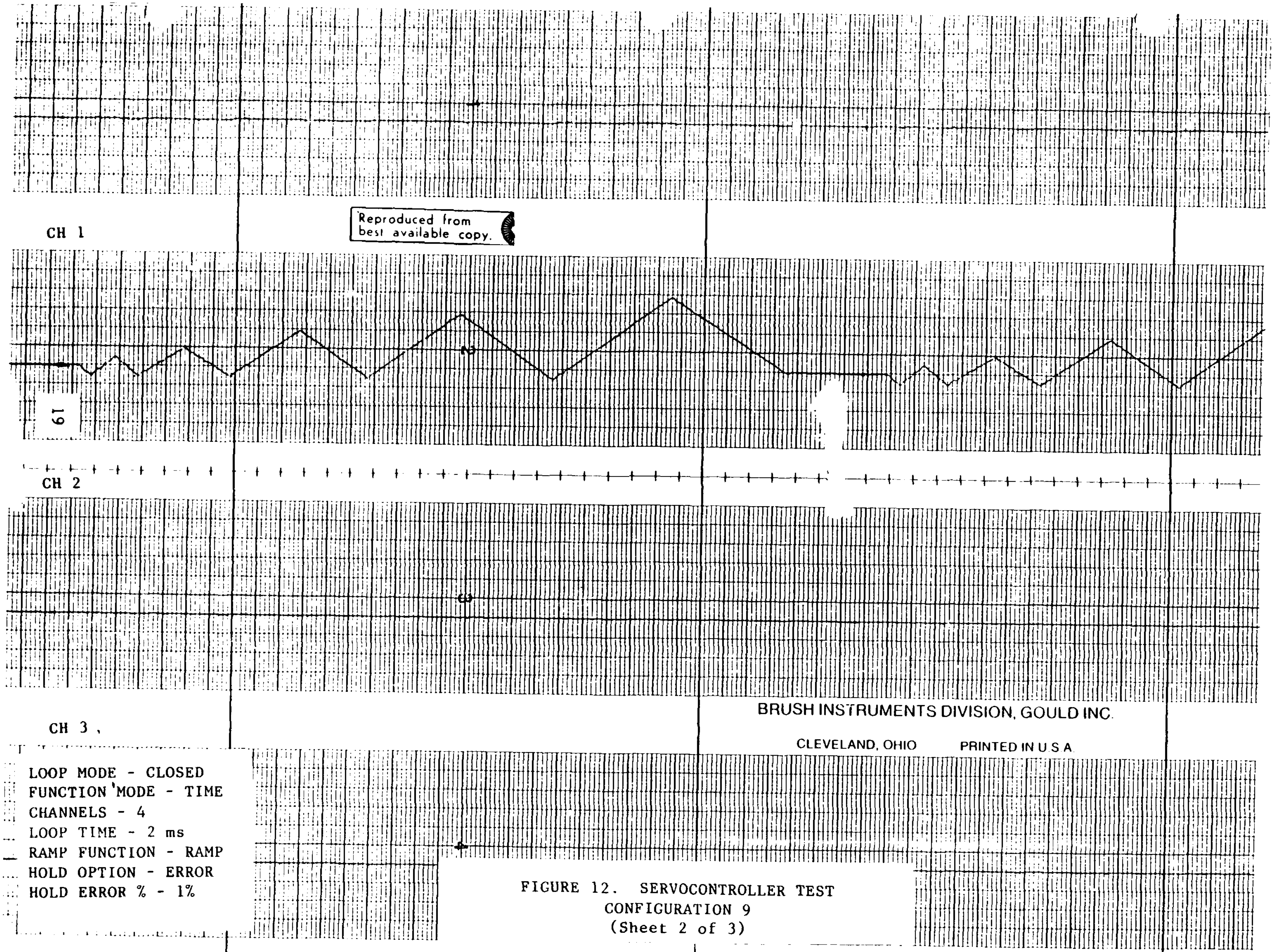

FIGURE 12. SERVOCONTROLLER TEST CONFIGURATION 9 (Sheet 2 of 3)

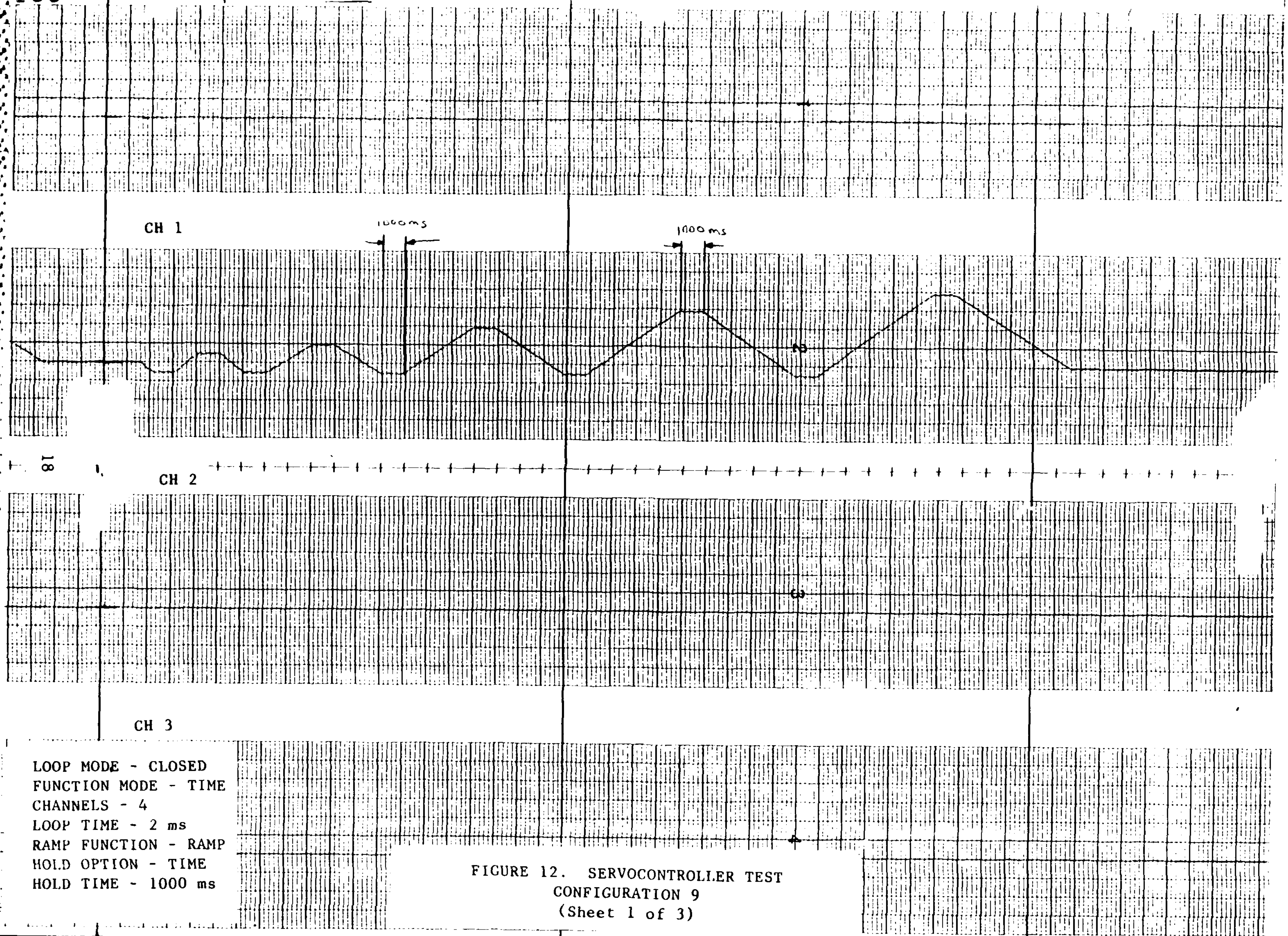

FIGURE 12. SERVOCONTROLLER TEST
CONFIGURATION 9
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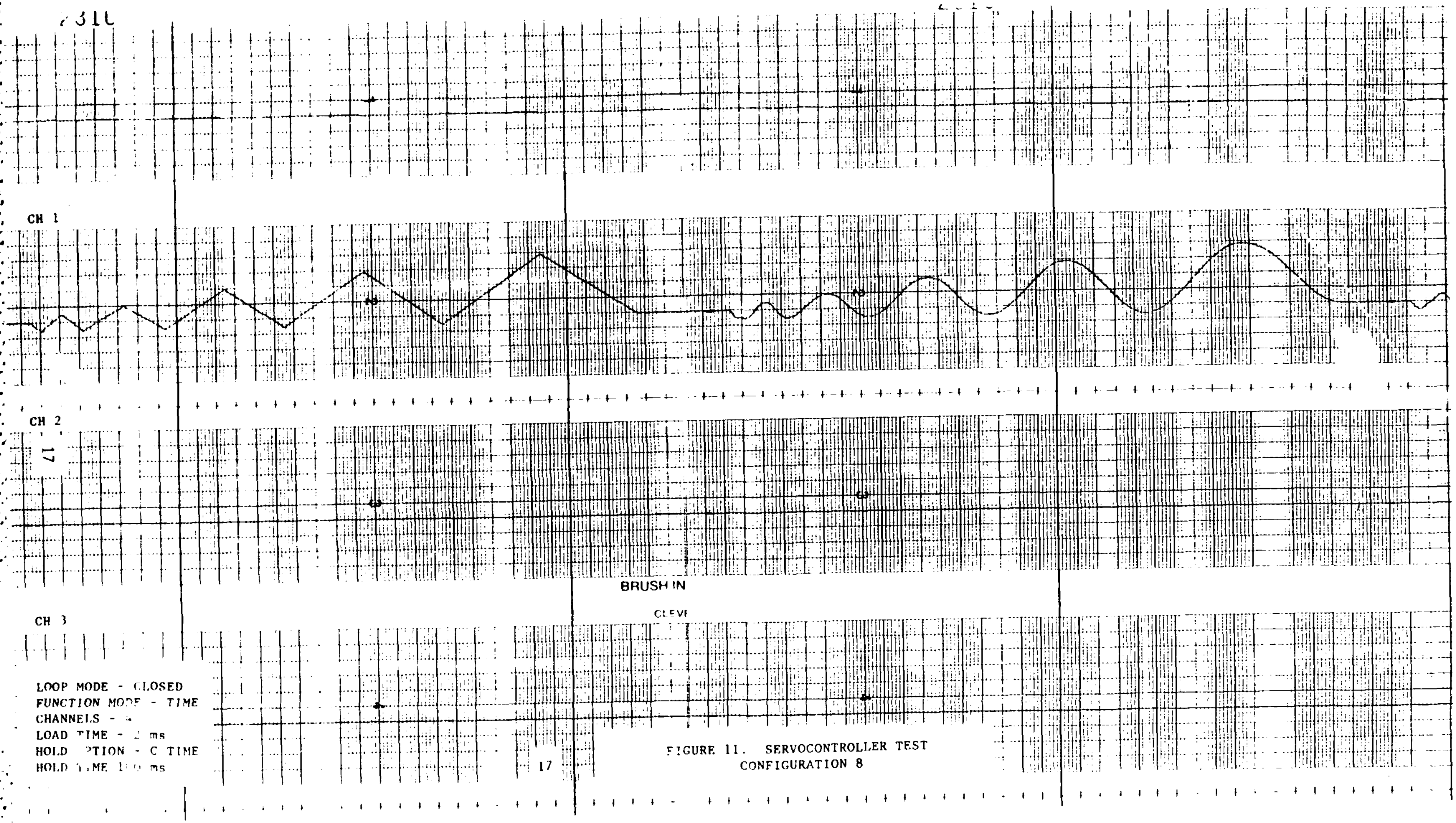


FIGURE 11. SERVOCONTROLLER TEST CONFIGURATION 8

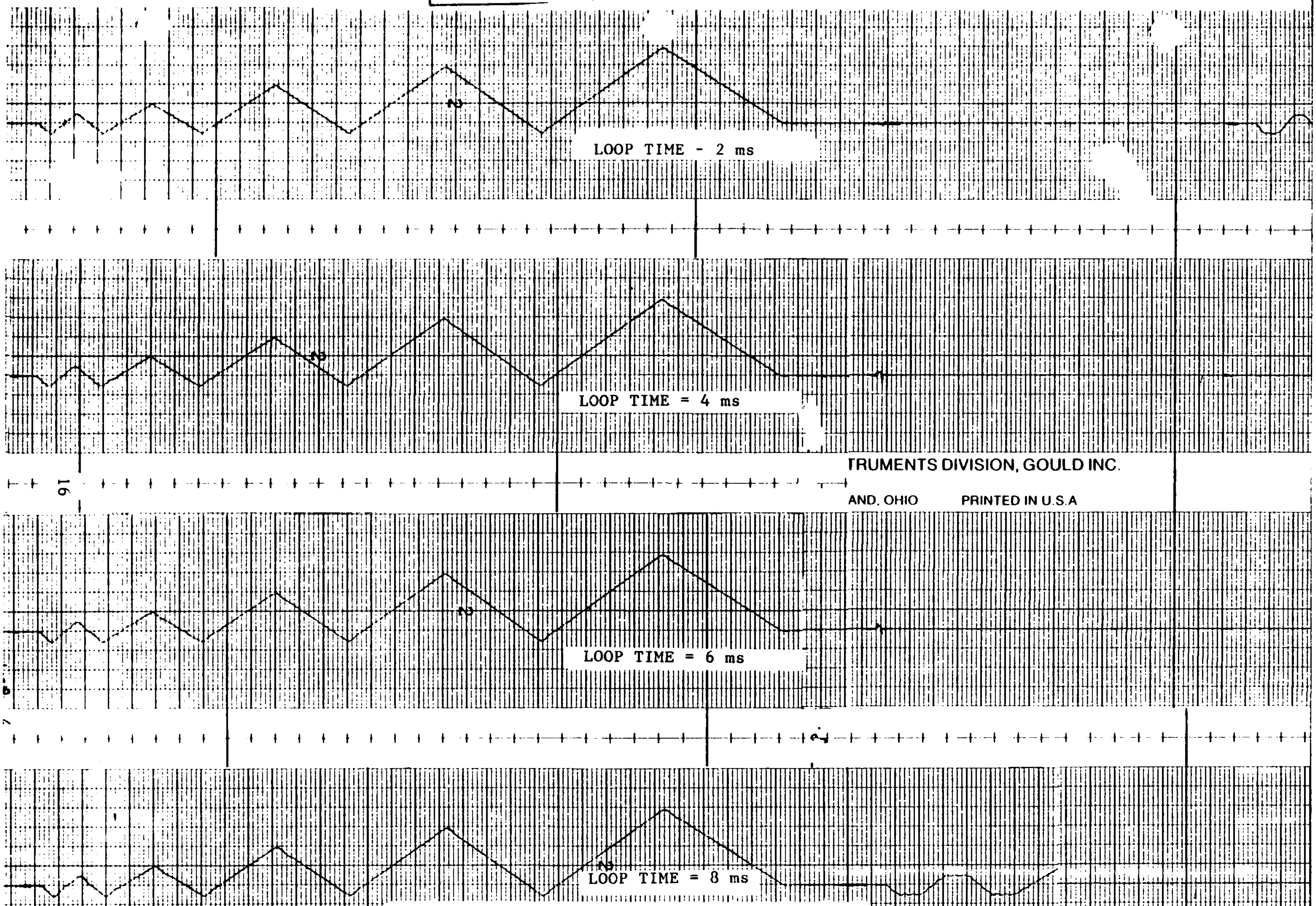


FIGURE 10. SERVOCONTROLLER TEST CONFIGURATION 7

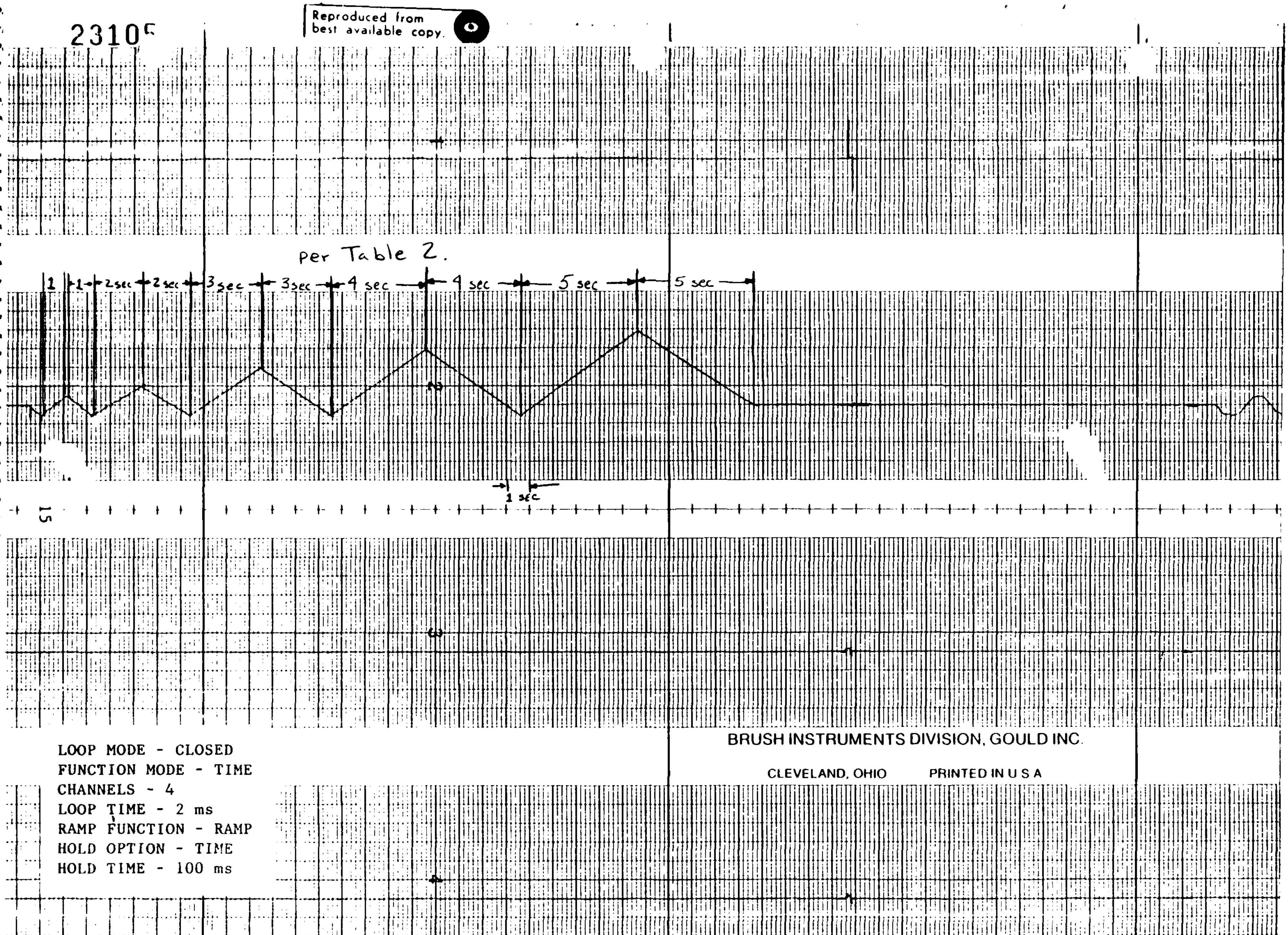


FIGURE 9. SERVOCONTROLLER TEST CONFIGURATION 6

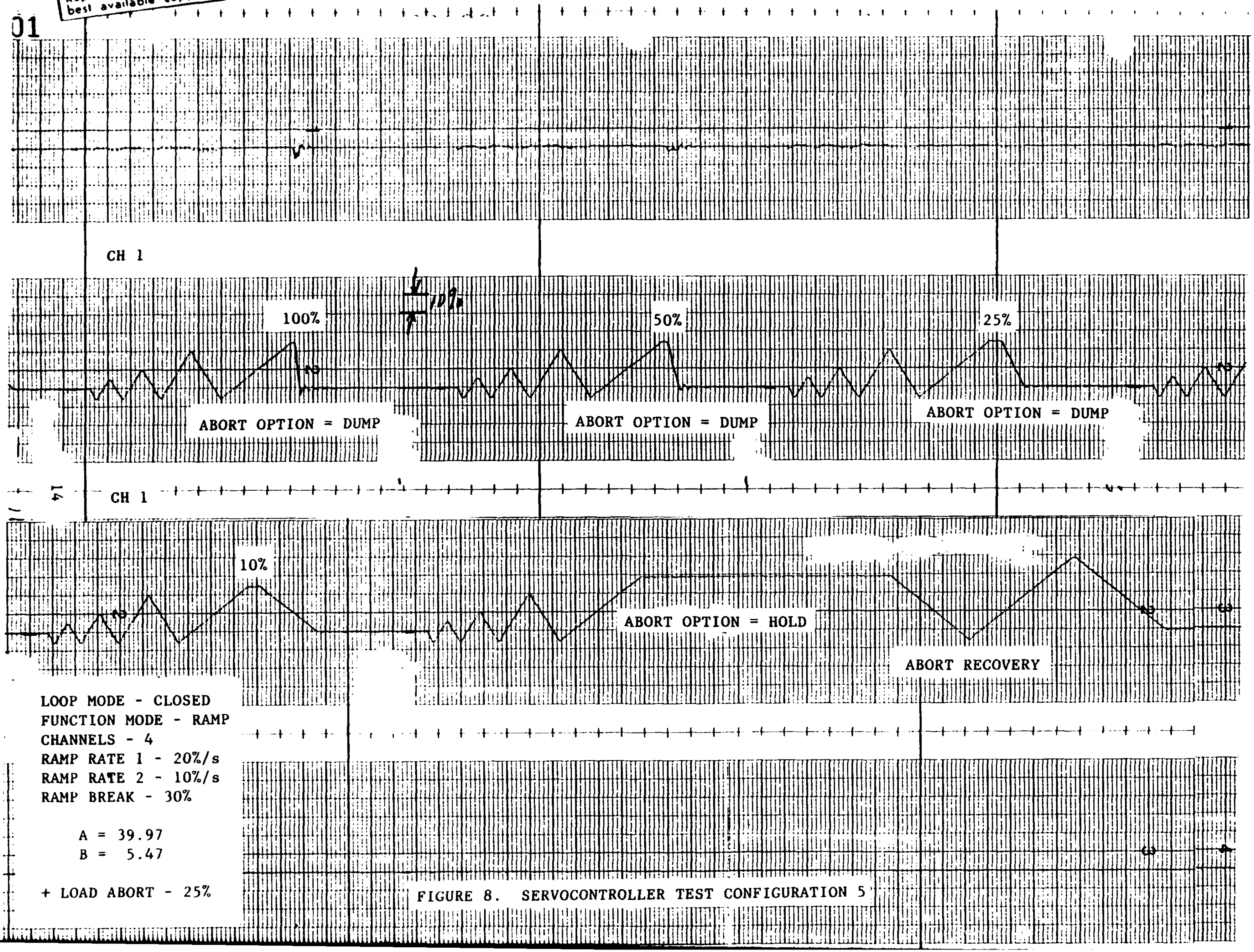


FIGURE 8. SERVOCONTROLLER TEST CONFIGURATION 5

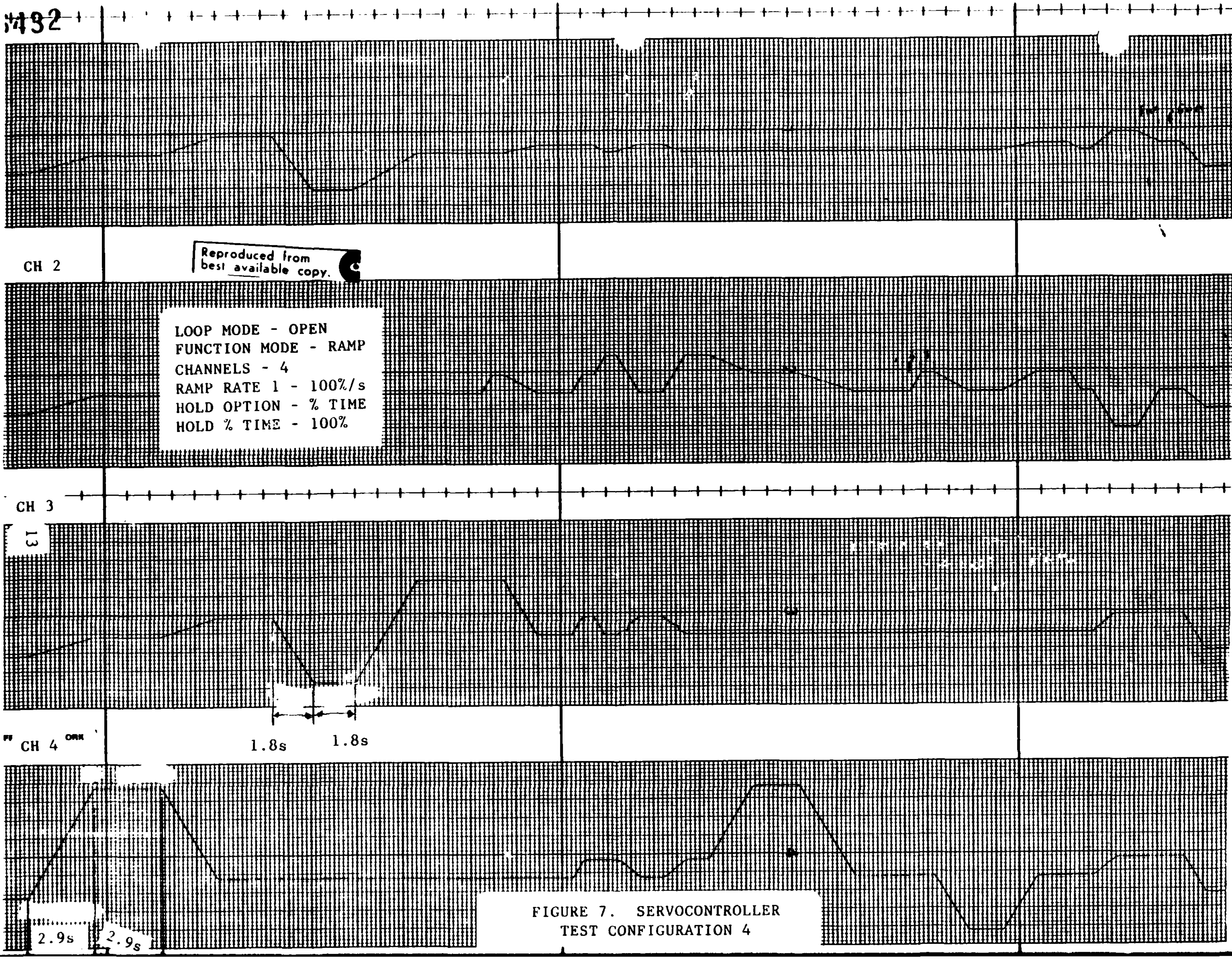


FIGURE 7. SERVOCONTROLLER TEST CONFIGURATION 4

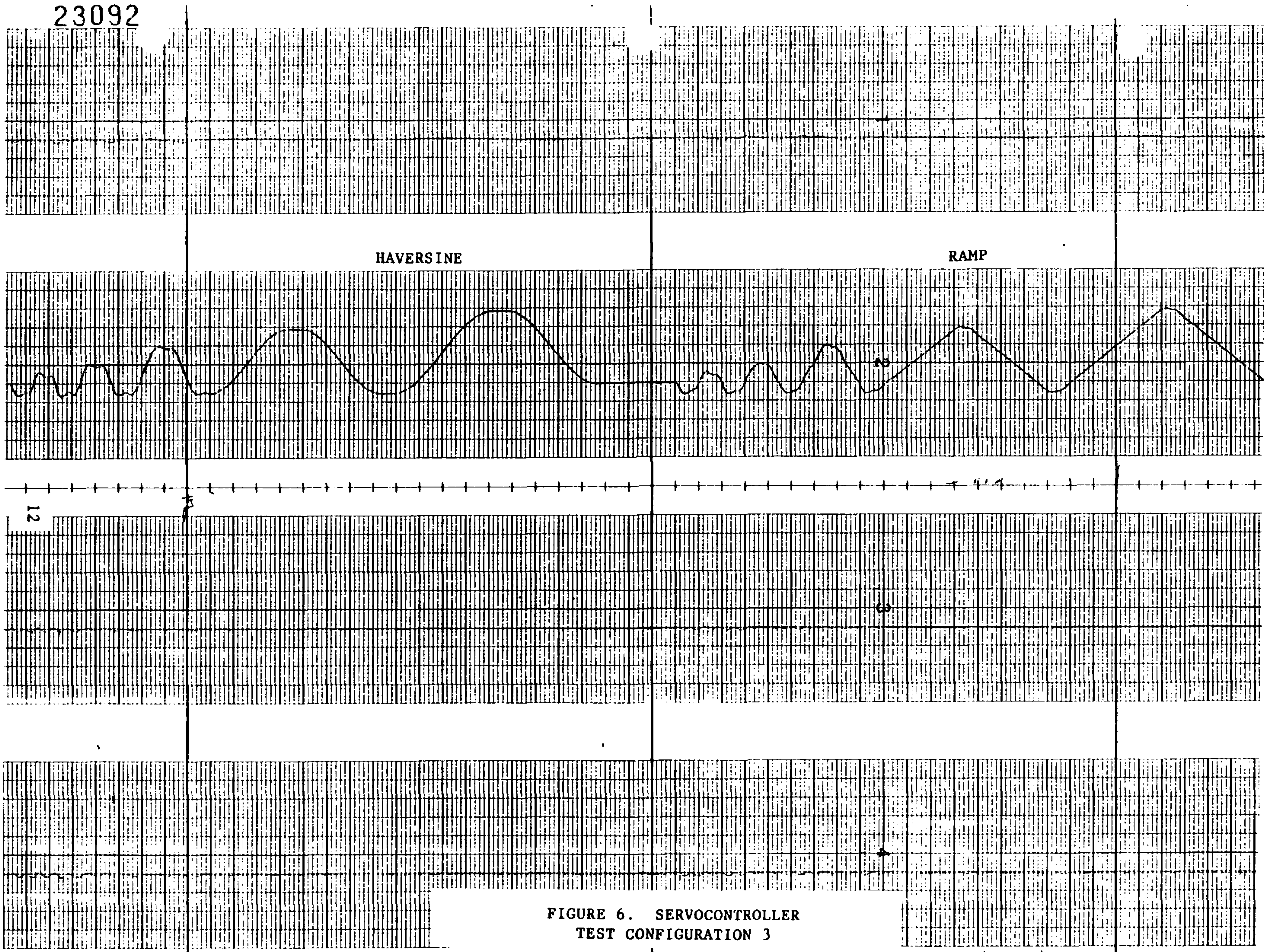


FIGURE 6. SERVOCONTROLLER TEST CONFIGURATION 3

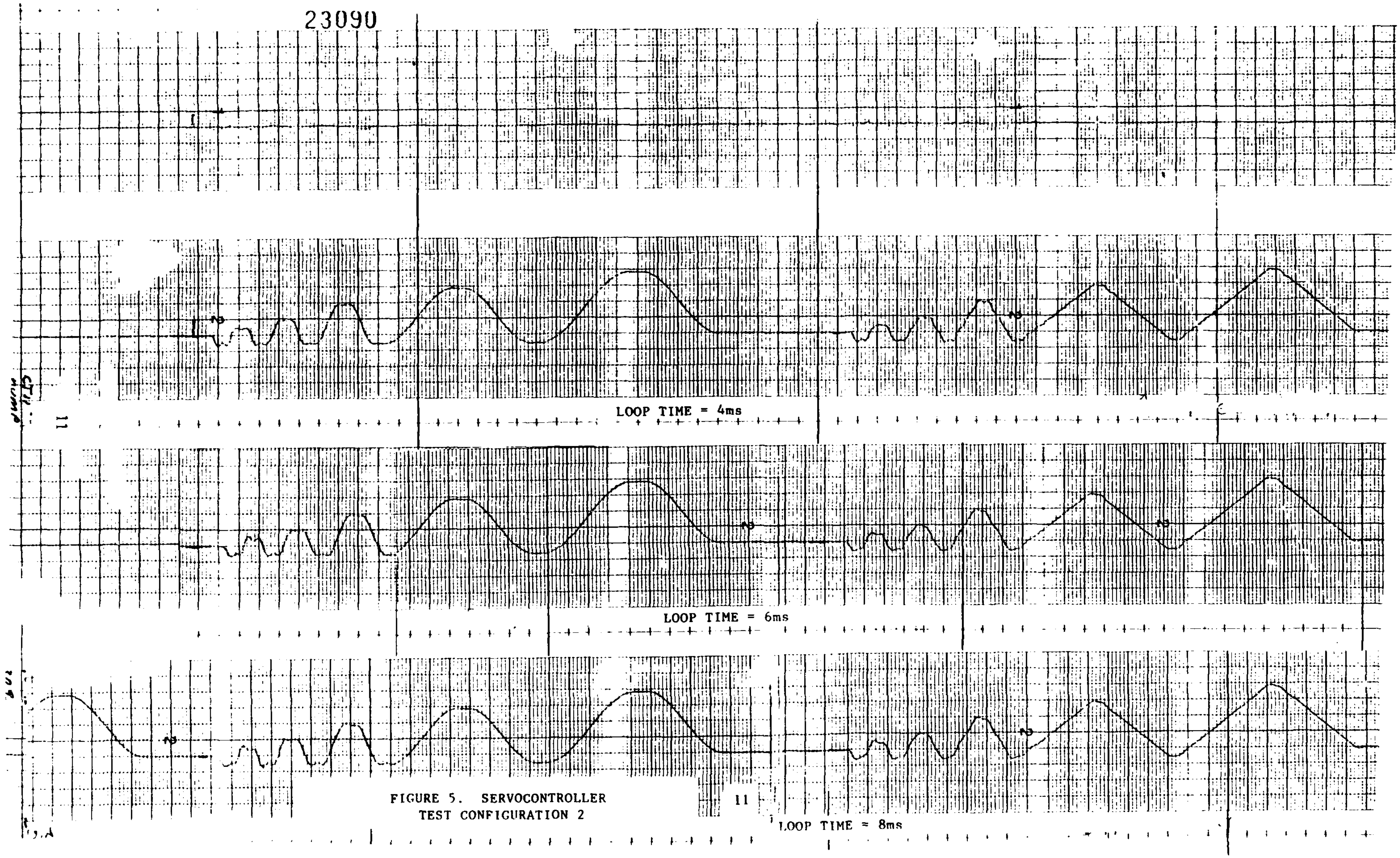


FIGURE 5. SERVOCONTROLLER TEST CONFIGURATION 2

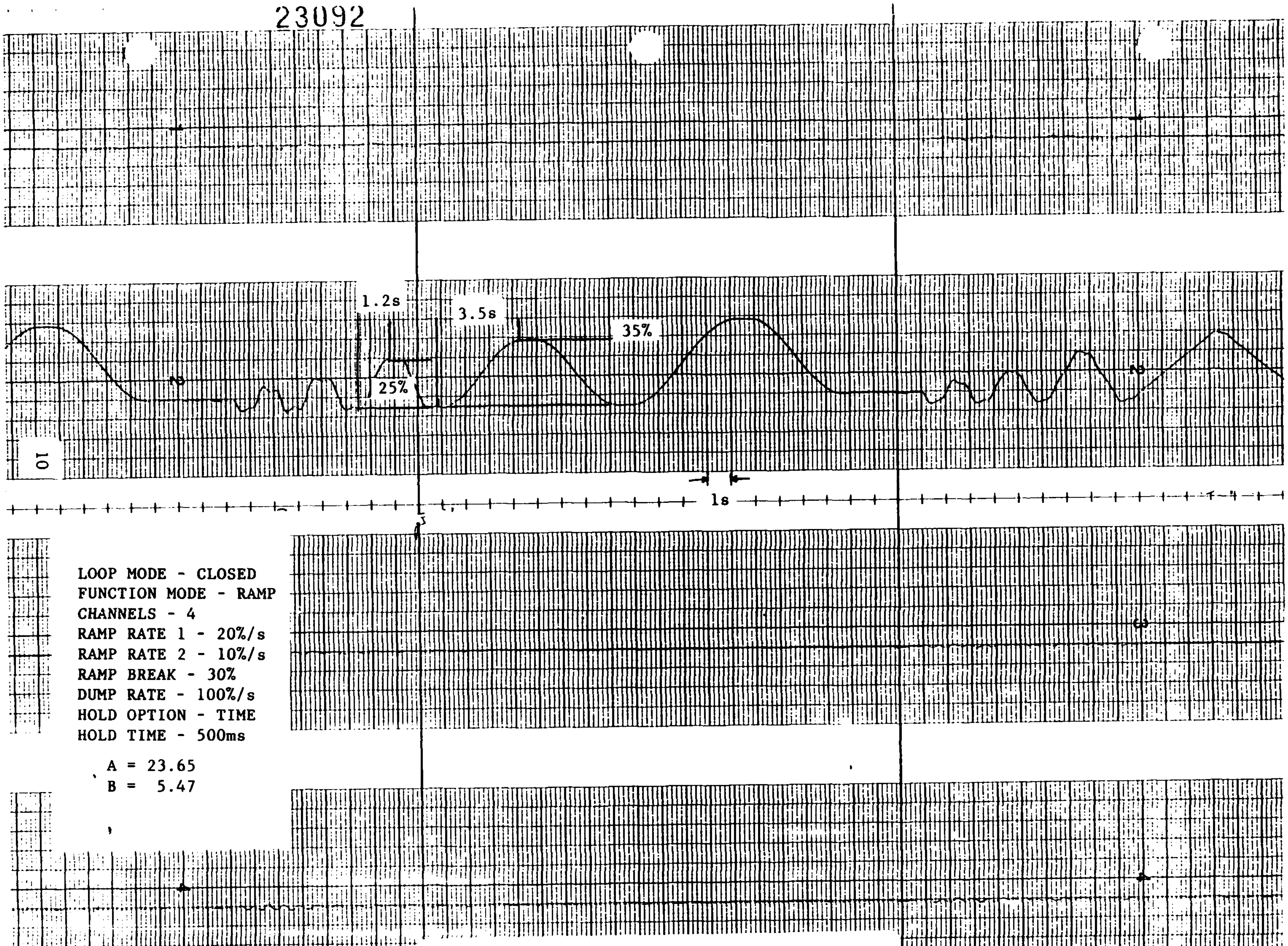


FIGURE 4. SERVOCONTROLLER TEST CONFIGURATION 1

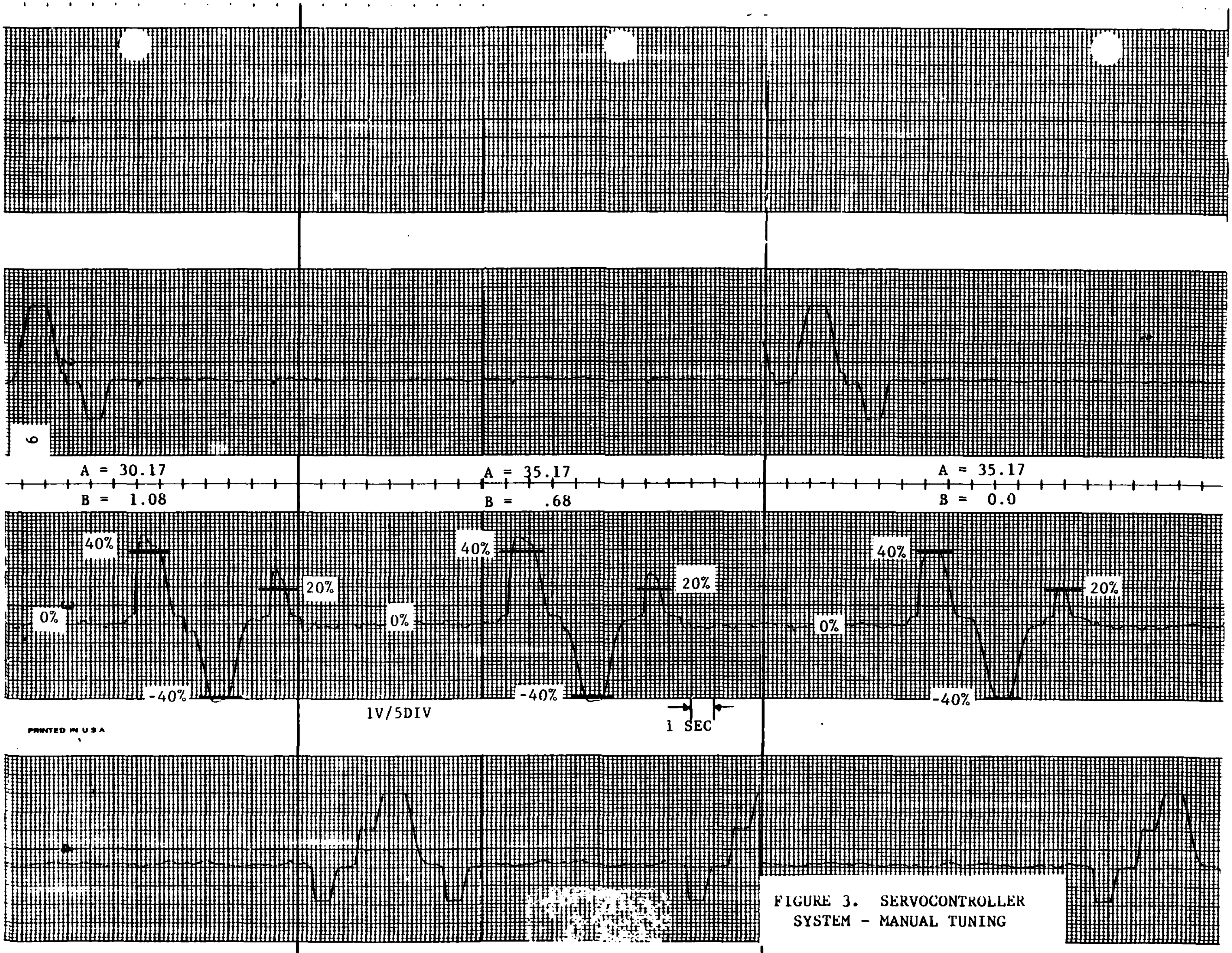


FIGURE 3. SERVOCONTROLLER SYSTEM - MANUAL TUNING

Table 1. Servocontroller Test Configurations

	RUN TYPE 1	2	3	4	5	6	7	8	9	10
System Mode	SA/S	SA/S	SA/S	SA/S	SA/S	SA/S	SA/S	SA/S	SA/S	SA/S
Loop Mode	Closed/Open	Closed/Open	Closed/Open	Closed/Open	Closed/Open	Closed/Open	Closed/Open	Closed/Open	Closed/Open	Closed/Open
Function Mode	RAMP/M	RAMP	RAMP	RAMP	RAMP	TIME/M	TIME	TIME	TIME	TIME
Channels	*	4	4	4	4	*	4	4	4	4
Ramp rate 1	*									
Ramp rate 2	*									
Ramp break	*									
Dump rate					*					*
Loop Time	2ms	*	2ms	2ms	2ms	2ms	*	2ms	2ms	2ms
Ramp Function	RAMP	RAMP	*	RAMP	RAMP	RAMP	RAMP	*	RAMP	RAMP
Hold Option	CTIME	CTIME	CTIME	*	CTIME	CTIME	CTIME	CTIME	*	CTIME
Abort Option	DUMP	DUMP	DUMP	DUMP	*	DUMP	DUMP	DUMP	DUMP	*
Hold Error %	.5	.5	.5	*	.5	.5	.5	.5	*	.5
Hold Time	25ms	25ms	25ms	*	25ms	25ms	25ms	25ms	*	.5
Hold / Time	10%	10%	10%	*	10%	10%	10%	10%	*	10%

SA/S - Stand Alone/Slave
* - Parameter under test
/M - Marker option used

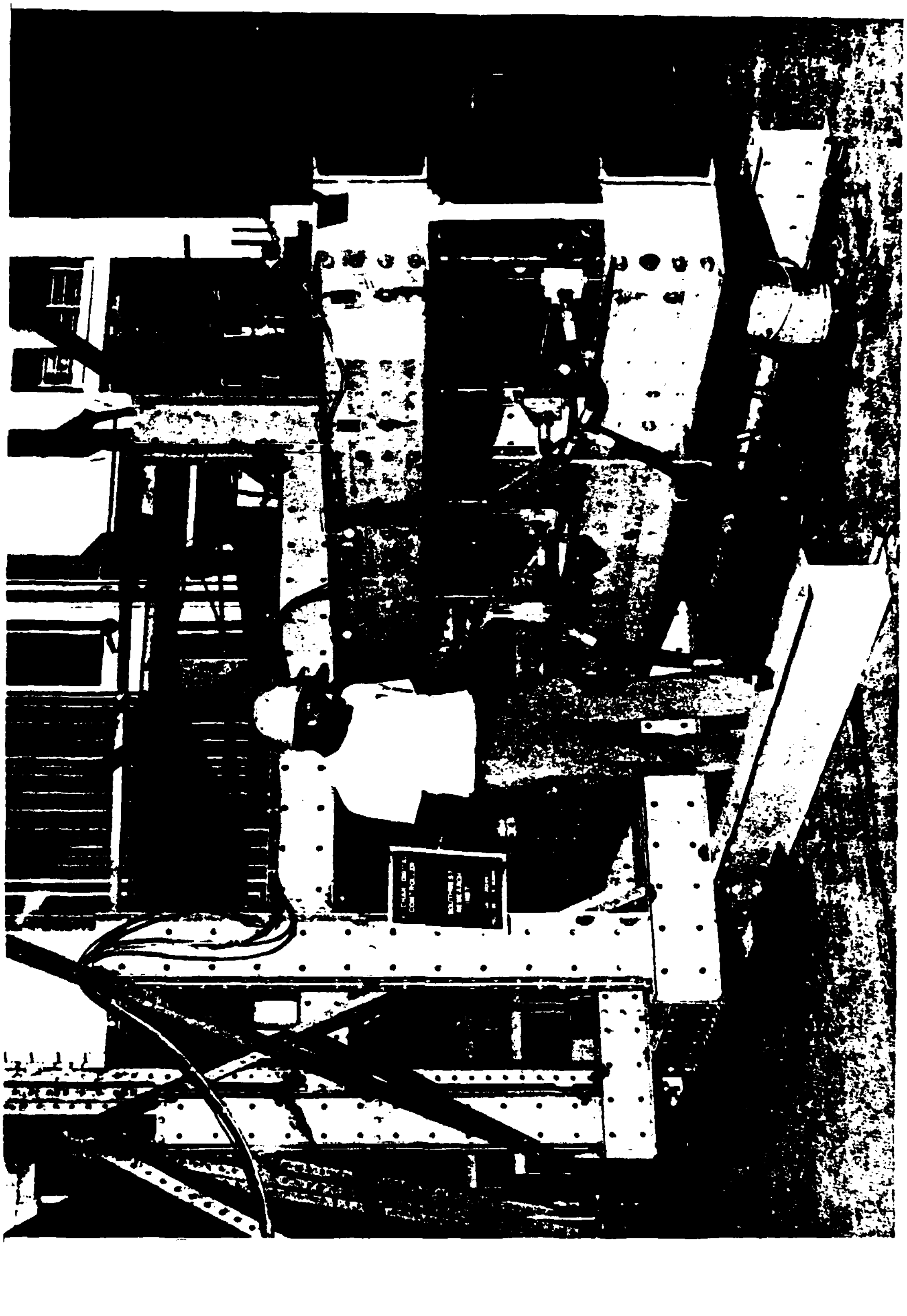


FIGURE 2. DIGITAL SERVOCONTROLLER TEST STAND

5.0 SERVOCONTROLLER SYSTEM EXPERIMENTAL VERIFICATION

5.1 Test Stand

The verification of the servocontroller system was performed on a test article designed by AFWAL engineers. It is shown in Figure 2. Four hydraulic cylinders were mounted between four horizontally cantilevered I-beams. Each cylinder would be controlled by a channel in the servocontroller. In this way, control of intercoupling effects as well as tension and compression loads could be demonstrated. One- and 2-gpm valves were used in the test stand. Load cells rated for 5000 lbs were used to trace the controller signals. As a result, brush recorders were used for the data recording.

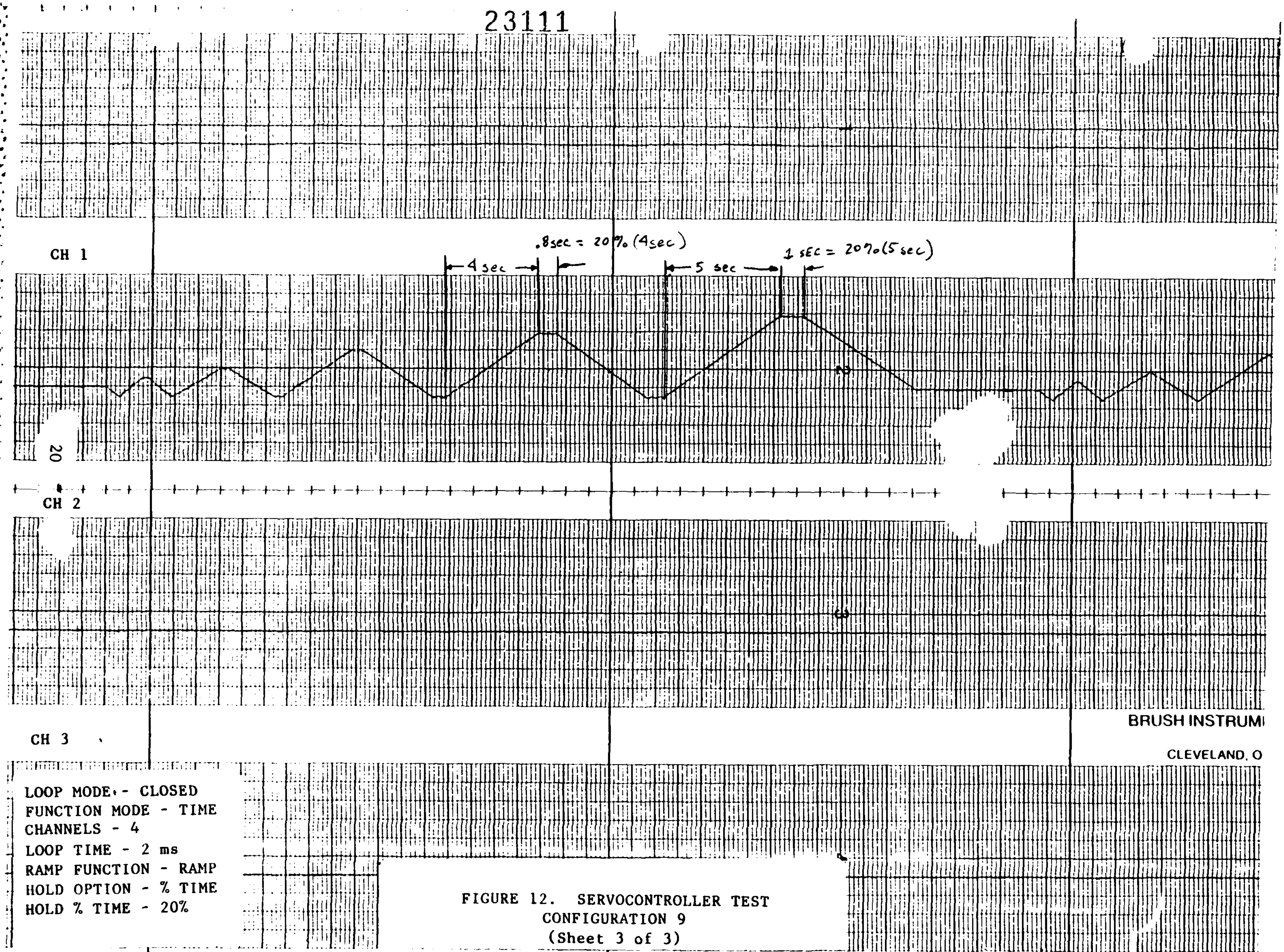
5.2 Test Configuration

The tests which were conducted with the servocontroller system were designed to verify and exercise the various features of the system. A set of ten test configurations were created, each testing a particular aspect of the system. The servocontroller test configurations are presented in Table 1. These tests were performed on the system by AFWAL personnel. The final ROMed version of the system was used for the execution of these tests. Previously, the system had been tested and verified in a piecemeal manner using the disk based version of the system. These final tests demonstrate the capabilities of the system in its ROMed configuration.

The lack of self-tuning capabilities requires that each channel be manually tuned. The tests performed on the servocontroller system were made without the benefit of manually tuned channels. Each test, which can be done without using a tuned channel, was used to evaluate a certain feature of the servocontroller. However, an example of a test run demonstrating manual tuning of a channel is included.

5.3 Test Results

The following figures are representative of the performance which the servocontroller is capable of achieving. Figure 3 demonstrates the increased performance due to manual tuning of Channel 3. Figures 4-13 demonstrate the system features as shown in Table 1. The load profile used for these tests is given in Table 2.



LOOP MODE - CLOSED
FUNCTION MODE - TIME
CHANNELS - 4
LOOP TIME - 2 ms
RAMP FUNCTION - RAMP
HOLD OPTION - % TIME
HOLD % TIME - 20%

FIGURE 12. SERVOCONTROLLER TEST CONFIGURATION 9 (Sheet 3 of 3)

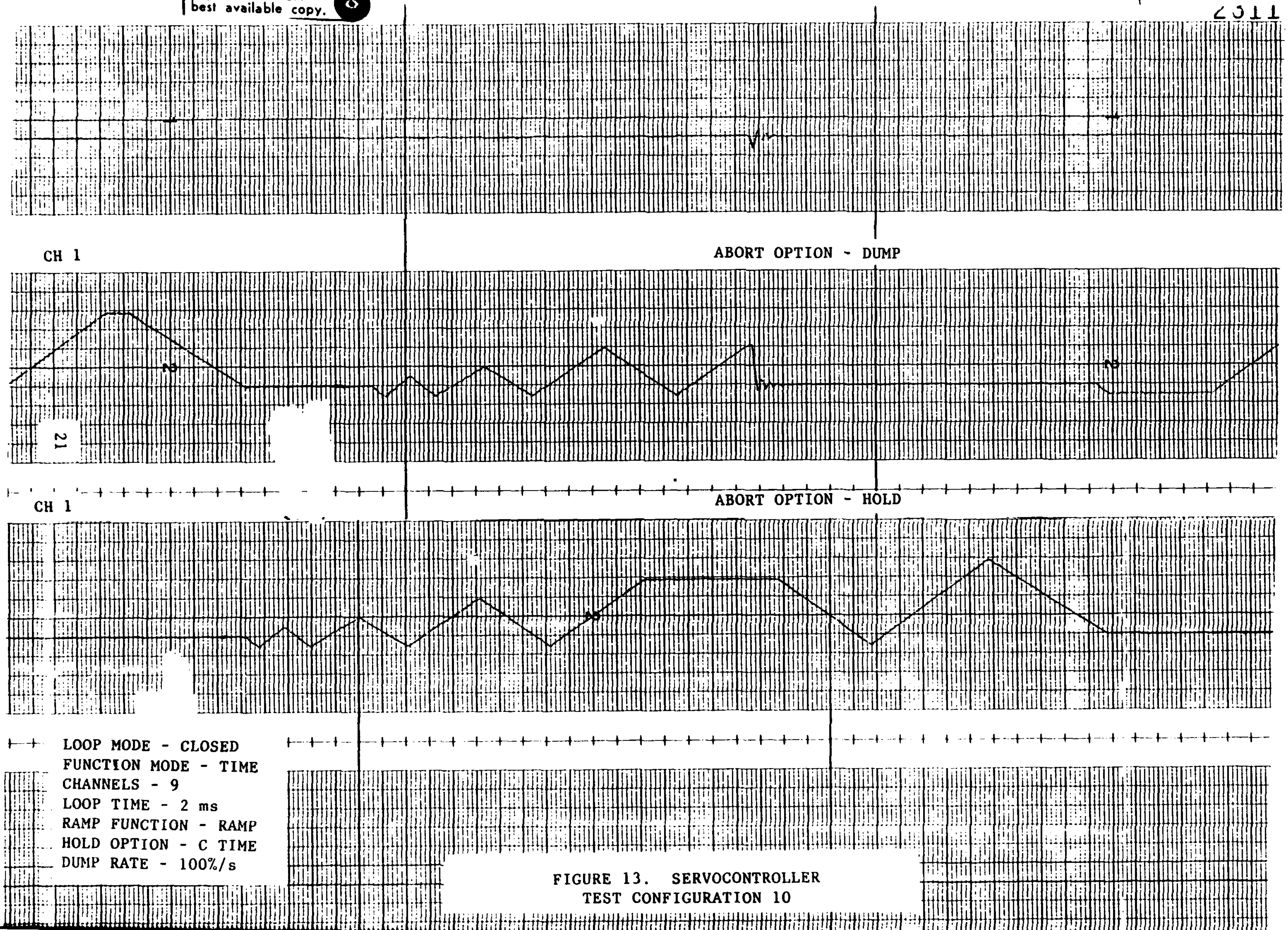


FIGURE 13. SERVOCONTROLLER TEST CONFIGURATION 10

TABLE 2. MANUAL ENTRY TEST SPECTRUM

LEVEL	1	2	3	4	5	6	7	8	9	10	11
CH1 %	-5	5	-5	10	-5	20	-5	30	-5	40	0
TIME(Δ)/SKIP	0.5/1	1./1	2./1	1./1	2./1	3./1	3./1	4./1	4./1	5./1	5./1

CH 2, 3, 4 - 0%

6.0 RECOMMENDATIONS/CONCLUSIONS

An implementation of direct digital control for air frame structures testing has been accomplished. The servocontroller system combines a stable control system with an operator interface which provides the capability to configure the system in various modes of operation. This versatility can be used to custom design load profiles depending on the requirements of the application. Information relevant to each control loop is presented on the terminal screen in a manner which is most useful to the operator. There is much potential for continued work in this area to enhance the system. The following list of items are enhancements which would add to the versatility and performance of the servocontroller system. They are listed in increasing degree of complexity in implementation.

(1) Develop and implement software which expands the hold option to force the system to an immediate hold upon receipt of a hold command. Currently, the system does not hold until it has reached a discrete programmed load level. This modification would hold the system at any point in the profile.

(2) Develop and implement software which would allow the servocontroller system to accept load commands from an external source through an analog-to-digital converter. The system could then be used in the same applications alongside analog controllers.

(3) Investigation and implementation of a self-tuning algorithm. A concentrated effort in this area is now possible given this servocontroller system. This feature would further facilitate the start-up procedures of a fatigue load test.

(4) Investigation and implementation of adding a higher speed microprocessor to the servocontroller system. A faster processor would allow for the increase of loop time or the number of channels to be controlled. The faster computational capability would also allow for the development of more sophisticated control algorithms.

(5) The addition of a Winchester hard disk system would expand the system's profile loading and data storage capabilities. It can also provide software development capabilities if added with a floppy disk backup system.

(6) The addition of a smart graphics terminal to the servocontroller system would relieve the system microprocessor of many of the screen update tasks. Control loop data could also be displayed in a more useful fashion (color, bar graphs).

(7) The development and implementation of control algorithms applied to pressure and temperature control would significantly increase the versatility of the servocontroller system. A system which can control load, temperature and pressure would be most useful in AFWAL.

(8) The development of a network of multiple servocontroller systems linked to a master computer would allow for application of the system to large scale structure testing.

(9) The investigation and development of a distributed network of single-board microprocessor based controllers would divide the tasks of control and operator interface. A host computer which linked the controllers would be used as the operator interface downloading only the setpoints to the controllers. The cost of adding channels would be decreased.

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