OPERATING MANUAL

FOR

MK-14A-55000

ECCENTRIC MASS SHAKER SYSTEM

Prepared for

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CAUTION!

THIS SYSTEM HAS BEEN CAREFULLY DESIGNED AND CONSTRUCTED TO ENSURE LONG-TERM, TROUBLE-FREE, SAFE USE BY OPERATORS WHO ARE KNOWLEDGEABLE IN ITS OPERATION. WITHOUT A THOROUGH UNDERSTANDING OF THIS SYSTEM'S OPERATING LIMITS, SERIOUS DAMAGE CAN RESULT TO ITS ELECTRONICS, ITS MECHANICAL COMPONENETS, AND, MOST IMPORTANTLY, TO THE PEOPLE AROUND IT. PLEASE READ THIS TEXT AND UNDERSTAND IT BEFORE ATTEMPTING TO USE THE SYSTEM. TAKE EVERY PRECAUTION TO ENSURE THE HEALTH AND SAFETY OF OTHERS.

NOTICE

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1.0 GENERAL SYSTEM DESCRIPTION

The MK-14A-55000 Eccentric Mass Shaker System consists of an eccentric mass shaker, a drive motor and speed reducer, a Danfoss VLT 5000 Adjustable Frequency Drive control system, and interconnecting cabling. The system is portable in the sense that it may be disassembled into individual elements, transported, then reassembled and attached to a test structure. Thirty amperes of 230-volt, 3-phase current is required for its operation.

The eccentric mass shaker, shown in Figure 1.1, is comprised of a base assembly, a rotating weight assembly, and an upper frame assembly. The weight assembly rotates about a vertical shaft to impart an omni-directional force (rotating force vector) in a horizontal plane to the test structure in proportion to its eccentricity (imbalance) and rotating speed squared. The shaker's eccentricity can be varied between 11,100 and 54,850 lb-in. in eight increments. Maximum force output is limited to 10,000 lb_f continuously and to 20,000 lb_f on an intermittent basis. Section 3.0 describes the process of establishing a test-specific eccentricity in greater detail.

The shaker is powered by a 7.5 hp (5 kW), 4-pole (1,800 rpm) induction motor. The speed of the motor is controlled by the Danfoss drive. The Danfoss drive is a vector type drive that allows the motor to produce almost full power at speeds as low as one RPM.

Subsequent sections discuss attaching the shaker to a test structure and shaker assembly, establishing and setting a test eccentricity, the shaker drive system, and a list of major components. The only required maintenance of the system is maintaining the oil level in the speed-reducing right-angle gearbox. It is assumed that the operators will periodically inspect all system elements and replace or repair worn elements as required.

(INSERT FIG. 1.1 HERE)

2.0 ATTACHING THE SHAKER TO THE TEST STRUCTURE AND SHAKER ASSEMBLY

Care must be taken to ensure that the MK-14A-55000 shaker is secured to the mounting surface. The shaker's footprint is hexagonal, approximately 8-ft, 6-in. across the flats. Vibration loosening of the attachment hardware governs the choice of anchorage, not the rated load of the anchorage. Thru-bolting is recommended when possible. The mounting surface should be flat and horizontal. Where flatness is unacceptable, grouting or shimming may be required to ensure adequate attachment.

A total of 14 attachment bolt holes have been provided through the shaker's bottom frame – two at each corner, as indicated in Figure 2.1 at Locations A through F, and two in the center. The shaker bottom frame is intended to be used as an anchor drilling template to ensure accurate anchor location. Assemble the elements shown in Figure 2.1 and the bottom bearing plate shown in Figure 2.2 using appropriate 5/8"-11 UNC bolts. Letters are stamped at the corners and intersections of the individual elements shown in Figure 2.1. Like letters must be paired or misalignment of the upper frame will occur. Assembly bolts should be tightened to 65 ft-lb. The shaker drive motor will be located between Corners A and F – position this face towards an open area.

Concrete anchoring is really two independent problems: 1) drilling a suitable hole, and 2) choosing and installing an anchor. Most types of anchors are designed to be installed in holes drilled with standard carbide masonry bits. Neither the standard carbide bits nor self-drilling anchors are effective when reinforcing bar (rebar) or sheet metal pouring framing is encountered. In these instances, diamond coring bits must be used. We have found it advantageous to employ the services of persons skilled in concrete coring when steel is encountered.

Of the many brands of concrete anchors available (Phillips "Red Head," Hilti, Diamond Keystone, Wej-it, Sup-R-Stud, etc.), we have found the Hilti anchor studs most effective. The attachment holes at each corner are 1.065-in. diameter, which permits use of a 7/8-in. carbide masonry bit. 3/4-in. Hilti studs can be used.

Periodically check attachment bolt tightness! Once vibration loosening has occurred, relocation of the shaker may be required to achieve adequate attachment.

Install the shaft and weight assembly (as shown in Figure 2.2) without the seven small weights. Four 3/4"-10 UNC x 2-1/2" bolts are required to attach the bottom bearing to the bottom bearing plate.

Recommended torque is 90 ft-lb. Next, place the large timing belt (P/N 14M3850-55) around the large timing belt pulley and then install the top frame members as shown in Figure 2.3. Again, like letters must be paired: top frame Corner “A” must be located above the bottom frame Corner “A”, etc., etc. Once all assembly bolts are installed, they may be tightened to a recommended 65 ft-lb.

Next, install the drive motor/reduction gearbox between Corners A and F, placing the large timing belt around the gearbox output pulley. Wedge the gearbox laterally to achieve a tension on the belt and secure it in place using 5/8”-11 UNC x 3-1/4 bolts with nuts. Rotate the weight a few times manually and note that the large belt is running rue on the large pulley. Adjust gearbox position to achieve alignment as required.

Lastly, install all the protective grating except one top frame upper section so that weights may be added prior to its installation. Now electrically connect the drive and control system and set the shaker’s eccentricity.

Figure 2.1

Figure 2.2

Figure 2.3

3.0 WEIGHT INSTALLATION AND ECCENTRICITY ADJUSTMENT

The limits of safe shaker operation (given adequate anchorage and test structure load capacity) are illustrated in Figure 3.1. Force output of the shaker is limited to 10,000 lb_f continuously and to 20,000 lb_f for a very brief period. Under no circumstances should the 20,000 lb_f limit be exceeded.

3.1 Weight Installation

The base weight, installed with the shaft and bearing assembly (see Figure 2.2), represents the minimum weight configuration. Its eccentricity is 11,100 in.-lb. As many as seven smaller weights may be added to the base weight to achieve a maximum eccentricity of 54,850 lb-in. Table 3.1 contains the eccentricity for each weight configuration and the shaker speeds at which the 10,000 lb_f and 20,000 lb_f limits are reached.

One or more small weights are added to the base weight by loosening the 1-1/4"-7 UNC x 10" bolts at each end of the upper retainer straps, rotating the straps away from the weight, installing the desired number of small weights and reinstalling and tightening the retainer strap bolts. One- through seven-inch spacers have been provided so that upper retainer straps can be kept horizontal and the outer bolts tightened with any number of smaller weights installed above the base weight. These large bolts should be tightened to 300 ft-lb. They are Grade 8 bolts with a yield greater than 120 ksi. Do not substitute bolts of a lesser strength.

TABLE 3.1: Eccentricity and Maximum Shaker Speed for Each Weight Configuration

Weight Configuration	Eccentricity (lb-in)	Max Speed (1) 10,000 lbf	Max Speed (2) 20,000 lbf
Base Weight Only	11,100	2.97	4.20
Base Weight + 1Weight	17,350	2.38	3.36
Base Weight + 2 Weights	23,600	2.04	2.85
Base Weight + 3 Weights	29,850	1.81	2.56
Base Weight + 4 Weights	36,100	1.65	2.33
Base Weight + 5 Weights	42,350	1.52	2.15
Base Weight + 6 Weights	48,600	1.42	2.01
Base Weight + 7 Weights	54,850	1.34	1.89

(1) Maximum Shaker Speed for Continuous Operation
(2) Maximum Shaker Speed for Intermittent Operation

3.2

Selecting a Test Eccentricity

Eccentricity (imbalance) of the shaker is a test parameter that is established prior to shaker operation. It is established by: 1) the limits of safe operation (see Figure 3.1), and 2) a desired maximum test frequency, or 3) a desired applied force at a specific frequency. An expression relating shaker force to running speed and eccentricity is shown in Equation (1):

$$F = 0.102 * (WR) * f^2 \qquad (1)$$

where: F = Force Output (lb_f)
WR = eccentricity (lb-in.)
f = shaker speed (Hz)

For example, when test requirements specify applying 5,000 lb_f to the test structure at 1.5 Hz, what weight configuration would you use and what would be the actual applied force? Rearranging Equation (1) to yield a desired eccentricity yields:

$$WR = F / (0.102 * f^2) = 5{,}000 / (0.102 * 1.5^2)$$

$$WR = 21{,}786 \text{ lb-in.}$$

Table 3.1 suggests that there are two weight configurations that will yield close to the desired 5,000 lb_f at 1.5 Hz. These are the base weight plus one small weight: 17,350 lb-in. and the base weight plus two small weights: 23,600 lb-in. With 17,350 lb-in. eccentricity, 3,980 lb_f will be achieved at 1.5 Hz; with 23,600 lb-in. eccentricity, 5,416 lb_f will be achieved at 1.5 Hz. The choice is yours; change the test specification to the value you like.

As a second example, it is desired to perform a frequency sweep to 3.0 Hz and not exceed 10,000 lb_f output. Can this be done and with what weight configuration? Again,

$$WR = F / (0.102 * f^2) = 10{,}000 / (0.102 * 3.0^2)$$

$$WR = 10{,}893 \text{ lb-in.}$$

The answer is no, the minimum eccentricity of the shaker is 11,100 lb-in. You will achieve 10,000 lb_f at 2.97 Hz. If this is close enough to 3 Hz, then you can proceed with the test.

Figure 3.1

4.0 OPERATING THE MK-14 SHAKER WITH THE DANFOSS DRIVE SYSTEM

The MK-14 Shaker is operated and controlled by a Danfoss VLT 5000 Adjustable Frequency Drive. This drive allows the MK-14 shaker to be controlled by either of two methods: Local mode or Remote mode. In Local mode, the user enters the control parameters directly into the Danfoss drive using the Danfoss drive menu system. In Remote mode, the user utilizes ANCO's FSINE software on a remote computer to communicate with the Danfoss drive via a wireless, spread-spectrum radio link. The FSINE software provides an interface for entering the shaker control parameters and allows the user to setup and conduct a forced vibration test over a given frequency range at user-defined step intervals. Refer to the FSINE Users Manual in Appendix B for additional information and instructions on using the FSINE software.

Copies of the complete operators guide for the Danfoss drives were included with the MK-14A shaker. However, this section details the basic steps required to operate and control the MK-14 shaker in both Local and Remote modes. Although the information listed in this section provides the user with the basic knowledge necessary to operate and control the MK-14 shaker, *it is highly recommended that the user review the Danfoss VLT 5000 Instruction Manuals to familiarize themselves with the operation of the Danfoss drives.*

4.1 Entering Parameters Directly Using the Danfoss Drive Menu System

Navigating and entering parameters using the Danfoss drive menu system is relatively straightforward and simple. The menu system is broken down into seven parameter groups, with each group containing a list of relevant parameters. The parameter groups are shown in Table 4.1

Table 4.1: Danfoss Drive Parameter Groups

Group #	Group Name
0	Operation and Display
1	Load and Motor
2	References and Limits
3	Inputs and Outputs
4	Special Functions
5	Serial Communication
6	Technical Functions

The parameter groups are navigated using the control keys on the Local Control Panel (see Appendix A for a description and summary of

using the Local Control Panel). With the drive powered, press the 'Menu' control key to enter Menu Mode. The third line of the display shows the current parameter group. Use the Left-Right arrow control keys to sequence through the parameter groups. When the desired Parameter Group has been selected, use the Up-Down arrow control keys to sequence through the parameters available for the current Parameter Group. The third line of the display now shows the selected parameter number and name while the fourth line shows the parameter's current value. To change a parameter value, press the 'Change Data' control key. If the parameter value is limited to a fixed data set, use the Up/Down arrow control keys to cycle through the available options. If the parameter value is a numeric data value, use the Left/Right arrow control keys to select the digit to change, then use the Up/Down arrow control keys to change the digit's value. Press the OK control key to accept the new value, or Cancel to return to the previous value.

4.2 Basic Danfoss Drive Parameters

Regardless of the operation mode of the shaker system, there are some basic system parameters that need to be entered and/or verified before operating the MK-14 shaker. Although they do not need to be entered each time the drive is powered, the user should verify that the parameters are correct for the current shaker configuration before operation. *Failure to verify these parameters could lead to inadvertent misuse of the system and potentially result in exceeding the rated force of the shakers and/or the structure to be tested*.

Table 6.2: Basic Danfoss Drive Parameters

Parameter Number	Parameter Name	Description	Suggested Value
415	Maximum Feedback	Max Allowable Motor RPM Command	1500 rpm
205	Maximum Reference	Reference Value for Specifying Motor Speed	1500 rpm
215	Preset Reference 1	Motor RPM Command, Expressed as Percentage of Maximum Reference (P205)	000.00%

Parameter 415 (P415) is the maximum allowable motor speed (in rpm). This parameter should always be set to 1500 rpm to prevent the shaker from exceeding its maximum rated speed of 4.2 Hz. Parameter 205 is the reference value used to calculate the operating speed of the shaker. This parameter should be set to the same value as P415, 1500 rpm. Parameter 215 is used to define the operating speed of the shaker as a percentage of the value entered into P205. This parameter should be set to 00.00% as a safety precaution to prevent the shakers from rotating in case the motors are inadvertently engaged.

4.3 Defining the MK-14 Operating Frequency

The operating frequency of the MK-14 shaker is controlled by defining the percentage of the maximum reference RPM specified in Parameter 205. This percentage is entered into Parameter 215 (00.00% format). For example, if P205 is set to 1500 rpm, then setting P215 to 5000 (50.00%), will result in a motor speed 750 rpm. The shaker frequency is then determined by applying the 6:1 gear reduction ratio configuration of the shaker. Using the previous example, with a motor speed of 750 rpm, the shaker speed will be 125 rpm, or 2.1 Hz. The following equation can be used to calculate the required percentage value for a given shaker speed:

Percentage Value = [Gear Ratio * 60 (sec/min) * Shaker Speed (Hz)] / [P205 (rpm)]

Example: If P205 is set to 1500 rpm, calculate the percentage value to be entered to achieve a shaker speed of 3.0 Hz.

Percentage Value = (6 * 60 * 3.0) / (1500) = 0.72 or 72.0%

Therefore, the user would enter the value 7200 (00.00% format) into P215 to achieve a shaker frequency of 3.0 Hz.

4.4 Monitoring MK-14 Shaker Performance With the Danfoss Drive Control Panel

In addition to viewing and setting the drive parameters used to control the MK-14 shaker, the Danfoss Local Control Panel can also be used to display the operating status of the drive. A complete list of the available display variables and instructions on using the display mode are included in Appendix A. Two of the key operating variables that can be displayed are the motor feedback rpm (FEEDBACK) and the drive frequency (FREQUENCY). The FEEDBACK variable displays the current motor speed in rpm. The FREQUENCY variable shows the drive output frequency, which can easily be translated into the shaker frequency by applying the following formula:

Shaker Frequency (Hz) = FREQUENCY / [2 * Gear Ratio]

For example, with the 6:1 Gear Ratio, if the FREQUENCY variable reads 30 Hz, the shaker frequency is 30 / (2 * 6) = 2.5 Hz. Note that the addition scale factor of 2 included in the above equation is necessary due to the fact that the output drive frequency is based on driving a 2 pole motor, while the MK-14A utilizes a 4 pole motor.

4.5 Operating the MK-14A Shaker in Local Mode

1. Verify that the eccentricity is known and documented.
2. Set the external ‘Inverter Control Switch’ on the front of the cabinet to ‘Local”.
3. Power the cabinet on.
4. Verify the Basic Danfoss Drive Parameters as discussed in Section 4.2.
5. Calculate the percentage value necessary to achieve the desired shaker frequency as described in Section 4.3 and enter this value into Parameter 215. Note that the shaker will not begin rotating until the MCR Reset button on the front of the cabinet has been pressed.
6. Ensure that all equipment and personnel are clear.
7. Press the MCR Reset button to initiate shaker operation.
8. During operation, the shaker frequency can be changed by entering a new percentage value into Parameter 215.
9. The shaker can be stopped by any of the following 3 methods:
    - Enter a value of 0000 into Parameter 215.
    - Press the “Stop / Reset” control key on the Danfoss drive control panel. The “Start” control key will need to be pressed to re-start the shaker.
    - Depress the “E-Stop” button on the front of the cabinet. This button will need to be pulled out and the MCR Reset button depressed in order to re-start the shaker.

4.6

Operating the MK-14 Shaker in Remote Mode

1. Verify that the eccentricity is known and documented.
2. Verify that the Wireless Systems Data Door Receiver is properly installed in the MK-14A cabinet. Use the numbered labels to ensure that the connectors are properly connected. Also ensure that the antenna is properly mounted on top of the cabinet and that the antenna cable is connected to the Data Door Receiver.
3. Set the external 'Inverter Control Switch' on the front of the cabinet to "Remote".
4. Power the cabinet on.
5. Verify the Basic Danfoss Drive Parameters as discussed in Section 4.2.
6. Connect the Wireless Systems Transmitter to the serial port on the remote computer and power on.
7. Use the FSINE software to define the test parameters. Refer to the FSINE Users Manual in Appendix B for instructions on using the FSINE software. Ensure that the proper values for the Max Motor RPM, Gear Ratio, and Eccentricity parameters are entered. *If these values are incorrect, the shaker may not operate at the desired speed and the maximum allowable force of the shaker may be exceeded, causing risk of damage to the shaker equipment, the test structure, and personnel.*
8. Once the all test parameters have been properly entered, initialize Radio Communication with the FSINE software.
9. Ensure that all equipment and personnel are clear.
10. Press the MCR Reset button to initiate shaker operation. Note that the shaker will not begin rotating until the test is started using the FSINE software.
11. Use the FSINE software to start the test. The test can be halted at any time by clicking the FSINE "E-STOP" button on the remote computer.
12. Upon completion of the test, the shaker will stop and the radio link will be severed.

5.0 SYSTEM COMPONENTS

The following is a tabulation of the major elements of the system.

Item	Manufacturer	Part Number
Shaft Flange Gearings	Sealmaster	MFC-55
Weight Shaft Timing Pulley	Uniroyal	P112-14M-55
Weight Pulley Bushing	Uniroyal	F x 3-7/16”
Large Timing Belt	Uniroyal	14M-3850-55
Gearbox Output Pulley	Uniroyal	P28-14M-55
Gearbox Output Bushing	Uniroyal	SK x 1-1/4”
Right Angle Gearbox	Browning	12 HB1-SF20
Gearbox Input Bushing	Uniroyal	SK x 1-1/4”
Gearbox Input Pulley	Uniroyal	P72-8M-50
Motor to Gearbox Timing Belt	Uniroyal	8M-1120-50
Motor Output Pulley	Uniroyal	P48-8M-50
Motor Output Bushing	Uniroyal	SD x 1-3/8”
Motor	Marathon	N/A

APPENDIX A:
Description and Summary of the Danfoss Local Control Panel

APPENDIX B:
FSINE Users Manual