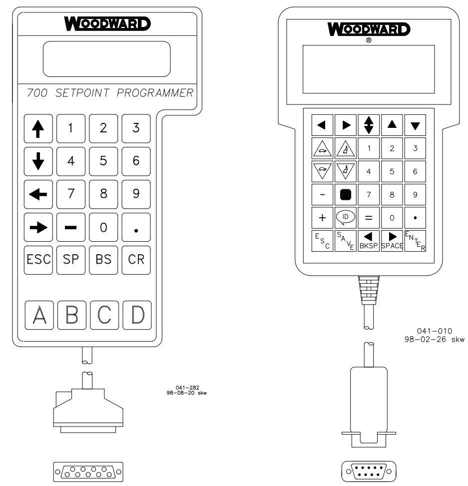
WOODWARD

Application Note 01304
(Revision A,8/1998)
Original Instructions



Dynamic Adjustment Procedure for 700-series Digital Controls

(700, 701, 701A, 702, 705, 721, 723, 723PLUS, 828)

General Precautions	**Read this entire manual and all other publications pertaining to the work to be performed before installing, operating, or servicing this equipment.** **Practice all plant and safety instructions and precautions.** **Failure to follow instructions can cause personal injury and/or property damage.**

Revisions	**This publication may have been revised or updated since this copy was produced. To verify that you have the latest revision, check manual *26311* , *Revision Status & Distribution Restrictions of Woodward Technical Publications*, on the *publications page* of the Woodward website:** **www.woodward.com/publications** **The latest version of most publications is available on the *publications page*. If your publication is not there, please contact your customer service representative to get the latest copy.**

Proper Use	**Any unauthorized modifications to or use of this equipment outside its specified mechanical, electrical, or other operating limits may cause personal injury and/or property damage, including damage to the equipment. Any such unauthorized modifications: (i) constitute "misuse" and/or "negligence" within the meaning of the product warranty thereby excluding warranty coverage for any resulting damage, and (ii) invalidate product certifications or listings.**

Translated Publications	**If the cover of this publication states "Translation of the Original Instructions" please note:** **The original source of this publication may have been updated since this translation was made. Be sure to check manual *26311* , *Revision Status & Distribution Restrictions of Woodward Technical Publications*, to verify whether this translation is up to date. Out-of-date translations are marked with ⚠. Always compare with the original for technical specifications and for proper and safe installation and operation procedures.**

Contents

Illustrations

Warnings and Notices

Important Definitions

This is the safety alert symbol. It is used to alert you to potential personal injury hazards. Obey all safety messages that follow this symbol to avoid possible injury or death.

- **DANGER**—Indicates a hazardous situation which, if not avoided, will result in death or serious injury.
- **WARNING**—Indicates a hazardous situation which, if not avoided, could result in death or serious injury.
- **CAUTION**—Indicates a hazardous situation which, if not avoided, could result in minor or moderate injury.
- **NOTICE**—Indicates a hazard that could result in property damage only (including damage to the control).
- **IMPORTANT**—Designates an operating tip or maintenance suggestion.

⚠WARNING

Overspeed / Overtemperature / Overpressure

The engine, turbine, or other type of prime mover should be equipped with an overspeed shutdown device to protect against runaway or damage to the prime mover with possible personal injury, loss of life, or property damage.

The overspeed shutdown device must be totally independent of the prime mover control system. An overtemperature or overpressure shutdown device may also be needed for safety, as appropriate.

⚠WARNING

Personal Protective Equipment

The products described in this publication may present risks that could lead to personal injury, loss of life, or property damage. Always wear the appropriate personal protective equipment (PPE) for the job at hand. Equipment that should be considered includes but is not limited to:

- **Eye Protection**
- **Hearing Protection**
- **Hard Hat**
- **Gloves**
- **Safety Boots**
- **Respirator**

Always read the proper Material Safety Data Sheet (MSDS) for any working fluid(s) and comply with recommended safety equipment.

⚠WARNING

Start-up

Be prepared to make an emergency shutdown when starting the engine, turbine, or other type of prime mover, to protect against runaway or overspeed with possible personal injury, loss of life, or property damage.

⚠WARNING

Automotive Applications

On- and off-highway Mobile Applications: Unless Woodward's control functions as the supervisory control, customer should install a system totally independent of the prime mover control system that monitors for supervisory control of engine (and takes appropriate action if supervisory control is lost) to protect against loss of engine control with possible personal injury, loss of life, or property damage.

NOTICE **Battery Charging Device**	**To prevent damage to a control system that uses an alternator or battery-charging device, make sure the charging device is turned off before disconnecting the battery from the system.**

Electrostatic Discharge Awareness

NOTICE **Electrostatic Precautions**	**Electronic controls contain static-sensitive parts. Observe the following precautions to prevent damage to these parts:** • **Discharge body static before handling the control (with power to the control turned off, contact a grounded surface and maintain contact while handling the control).** • **Avoid all plastic, vinyl, and Styrofoam (except antistatic versions) around printed circuit boards.** • **Do not touch the components or conductors on a printed circuit board with your hands or with conductive devices.** **To prevent damage to electronic components caused by improper handling, read and observe the precautions in Woodward manual *82715*, *Guide for Handling and Protection of Electronic Controls, Printed Circuit Boards, and Modules*.**

Follow these precautions when working with or near the control.

1. Avoid the build-up of static electricity on your body by not wearing clothing made of synthetic materials. Wear cotton or cotton-blend materials as much as possible because these do not store static electric charges as much as synthetics.
2. Do not remove the printed circuit board (PCB) from the control cabinet unless absolutely necessary. If you must remove the PCB from the control cabinet, follow these precautions:
   - Do not touch any part of the PCB except the edges.
   - Do not touch the electrical conductors, the connectors, or the components with conductive devices or with your hands.
   - When replacing a PCB, keep the new PCB in the plastic antistatic protective bag it comes in until you are ready to install it. Immediately after removing the old PCB from the control cabinet, place it in the antistatic protective bag.

Dynamic Adjustment Procedure for 700-series Digital Controls

Introduction

The following procedures are a guide to adjusting the dynamics of Woodward 700-series Digital Speed Controls (700, 701, 701A, 702, 705, 721, 723, 723PLUS, 828). Refer to the specific control manual for instructions on the use of your Hand Held Programmer and set point adjustment (menu) procedures.

Notes on Dual Dynamics

If the unit will be operated in dual mode applications, it is desirable to use the dual dynamics feature of the control. Dual mode applications include generator sets operated in both isolated bus and utility parallel applications, dual-fuel engines, and mechanical drive systems with clutches engaged or disengaged.

Connect the discrete input which switches dynamics to a relay operated when the breaker closes, fuel changeover occurs, or the clutch is engaged. Set up the primary set of dynamics for operating in the first mode, and then repeat the setup procedure on the alternate set of dynamics in the second mode.

For gas fueled engines, or other engines that are difficult to control at no-load, the dual dynamics feature allows one set of dynamics for control at no-load, and the second to be used when load is applied. Examples include a setup with high stability to control very low frequency hunting at no-load, or a generator set that requires one dynamic setting to synchronize efficiently and another setting for proper operation under load.

Pre-Start Settings

This section describes the dynamic set points and provides a preliminary value for each set point prior to starting the engine. If a first set of dynamics in a control has already been tuned, or a control on an identical engine has been previously set up, those values may be used for pre-start settings if desired.

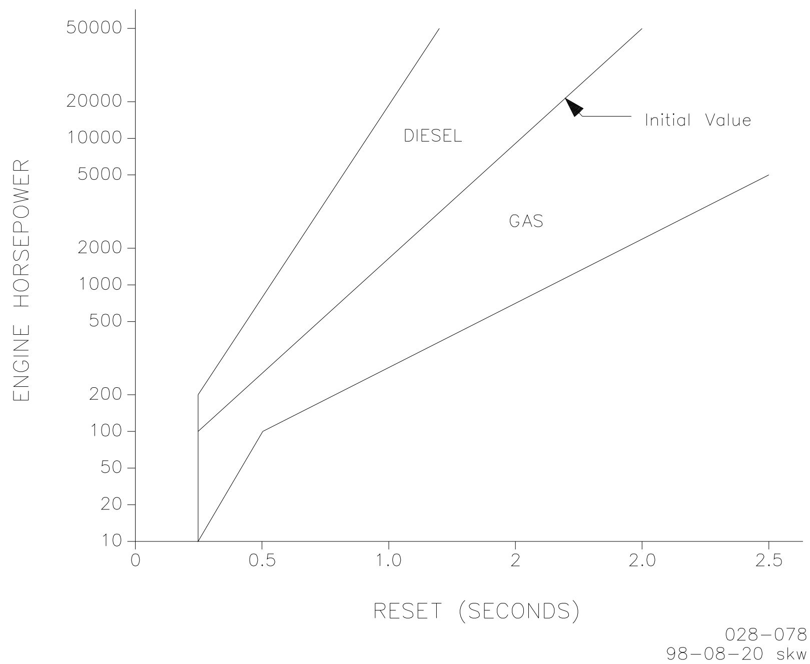
1. **GAIN** is the proportional gain term in a PID (Proportional, Integral, Derivative) controller. **GAIN** determines how fast the control responds to an error in speed when the speed reference is changed or a load disturbance occurs. A value too high (over 100%) will result in sustained oscillations in speed. A value too small (less than 50%) will result in poor control performance.

   Preliminary Value: Diesel—0.10
   (700, 701, 701A, 702, 705, 721) Gas—0.01

   Preliminary Value: Diesel—10
   (723, 723PLUS, 828) Gas—1

2. **RESET** is the integral gain term in the PID controller. **RESET** compensates for lags in the engine control loop. It prevents slow hunting at steady state and controls damping when speed error returns to zero after a speed disturbance. A value too high (over 100%) will result in large, low frequency oscillations in engine speed. The actuator will tend to “bang” from stop-to-stop. A value slightly too high (above 50%) is indicated by an over-damped condition, or the speed error returning too slowly to zero. A value slightly too low is indicated by an under-damped condition, or the speed overshooting the reference and returning, possibly with several damped oscillations. A value too low will result in slow, low amplitude hunting of speed about the speed reference.

   Preliminary Value: Set according to the initial value line in the following chart.



IMPORTANT **For diesel engines, the final RESET value will typically be near or below (left of) the initial value. For gas engines, the final RESET value will typically be near or above (right of) the initial value. A final RESET value less than 0.25 seconds is not recommended.**

3. **ACTUATOR COMPENSATION** is the derivative term in the PID controller. It adjusts the rate of change in actuator output when a load disturbance occurs. A value too low will result in a slow and under-damped control. A value too high will result in excessive high frequency actuator movement.

   Preliminary Value: 25% of **RESET** value (0.25 x **RESET**)

4. **GAIN RATIO** works in conjunction with **WINDOW WIDTH** to provide higher control gain for load transients outside the window, and lower control gain inside the window at steady state. The base **GAIN** set point defines the control gain inside the window. **GAIN** is multiplied by the **GAIN RATIO** set point value when outside the window. **GAIN RATIO** should be turned off by setting its value to 1.0 during initial dynamic adjustment.

   Preliminary Value: 1.0

5. **WINDOW WIDTH** works in conjunction with **GAIN RATIO** as described above. **WINDOW WIDTH** is not absolute, but an anticipated value. When the control senses a change in speed that it predicts will cause a speed error exceeding the **WINDOW WIDTH**, the control gain is set to the value determined by multiplying **GAIN** by **GAIN RATIO**. This allows the control to act quickly on a transient. When speed error is returning to zero after a disturbance, the control also predicts the error entering the window and automatically reduces control gain to the value determined by **GAIN**. The amount of anticipation is a function of **RESET**, higher values of **RESET** resulting in faster anticipation. **WINDOW WIDTH** should be disabled during preliminary dynamic adjustments by setting **GAIN RATIO** to 1.0.

   Preliminary Value: 3% of rated speed reference

6. **GAIN SLOPE** works in conjunction with **GAIN BREAKPOINT** to increase or decrease the control gain as a function of engine load. **GAIN SLOPE** can help compensate for non-linear fuel systems on some gas fueled engines. **GAIN SLOPE** can also improve stability and response during load rejections by providing higher gain at higher engine loads. **GAIN SLOPE** modifies the control **GAIN** value only when the actuator output is greater than the **GAIN BREAKPOINT** set point by the equation:

   Control Gain =
   GAIN x [1.0 + (actuator output – **GAIN BREAKPOINT**) x **GAIN SLOPE**]

IMPORTANT

The gain slope function is effective only when the actuator output of the control is a function of engine load. It is desirable to set up the fuel system to provide at least a 50% change in actuator output from no-load to full-load (e.g., 25% to 75%). Smaller changes and the effects of turbochargers on gas and diesel engines, and boost-related pressure regulators on gas engines, may reduce or defeat the effectiveness of the gain slope function. For preliminary dynamic adjustments, the gain slope function should be disabled by setting the GAIN SLOPE to 0.0.

   Preliminary Value: 0.0

7. **GAIN BREAKPOINT** works in conjunction with **GAIN SLOPE** as described above to define the point at which the **GAIN SLOPE** affects the actuator output. **GAIN SLOPE** is typically a positive value resulting in an increase in gain as fuel is increased. **GAIN BREAKPOINT** is normally set to match the actuator output obtained at no-load. This prevents the control gain from dropping too low during load rejections when the actuator output may go to 0%. For preliminary dynamic adjustments, the gain slope function should be disabled by setting **GAIN SLOPE** to 0.0.

   Preliminary Value: 25%, or equal to no-load actuator output if known

8. Repeat the procedure above for the second set of dynamics (if available).

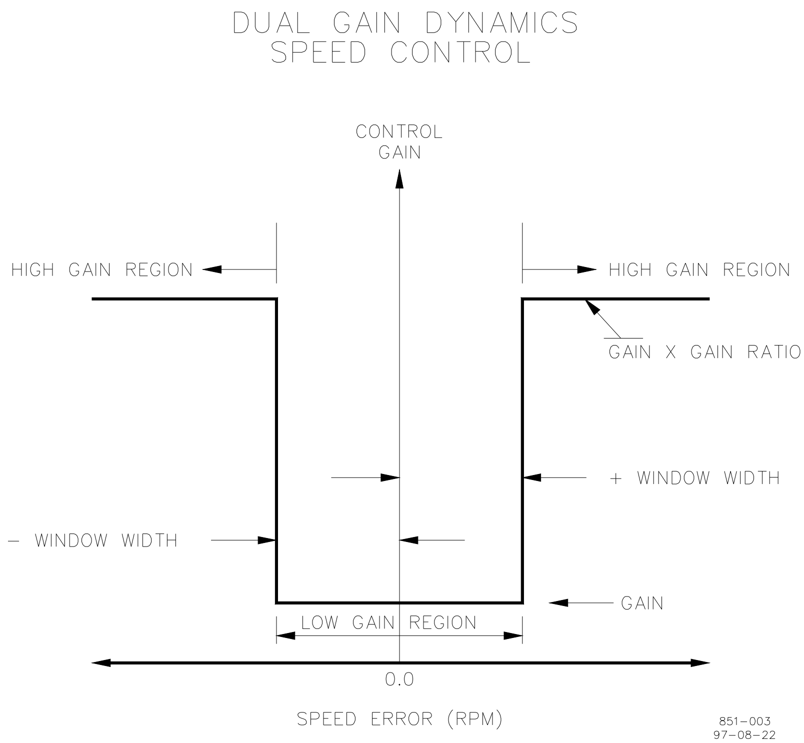


Figure 1. Control Gain as a Function of Speed Error

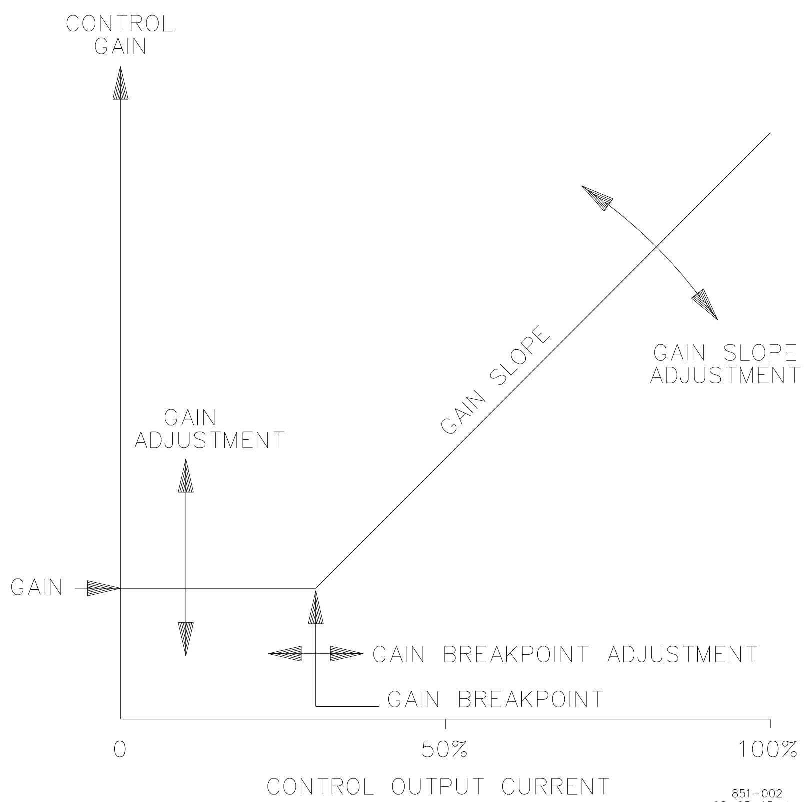


Figure 2. Control Gain as a Function of Control Output

Dynamic Adjustments

This section describes the dynamic adjustment procedures. Make preliminary adjustments with the engine at no load.

1. Select the **GAIN** set point on the dynamics menu. Be prepared to reduce the set point if instability should occur on the initial start-up.

2. Start the engine. If the engine is unstable, reduce the **GAIN** set point by 50%. If the instability decreases, reduce the **GAIN** set point in 50% steps until stability is achieved.

   If stability decreases as indicated by a slow hunt when reducing the **GAIN**, reduce the **RESET** and **COMPENSATION** set points each by 50% and double the gain. Repeat this procedure to obtain stable control.

3. Increase the **GAIN** value until the engine begins to hunt. Count the frequency of the hunt. (Count the number of oscillations per second.) Then reduce the **GAIN** value to 50% of the **GAIN** value where the engine started to hunt. The engine should be stable.

4. Set **RESET** to the inverse of the engine hunt frequency, that is:

   RESET = 1/(number of oscillations per second)

   Example: If the engine oscillated at 2 oscillations per second, then
   RESET = 1/2 = 0.5

5. Set **COMPENSATION** to 25% of **RESET**.

6. Increase the **GAIN** setting until the engine begins to hunt, then reduce to 50% of the value where the hunt began.

This procedure will usually provide satisfactory control performance. Some engines, however, may be difficult to control at no load. If a slow, low-amplitude hunt occurs, first reduce **GAIN** by 50%, and then increase **RESET** by 100%. If this fails to reduce the low amplitude hunt, check for sticking linkages, pressure regulators, etc.

Dynamic Adjustments may now be made with the engine under load. If the dual dynamics feature is used for no-load and loaded applications, the following adjustments apply to the second set of dynamics. Otherwise, they will provide a “trimming” procedure to the dynamics set above.

Adjustments for generator sets are given first, followed by a procedure for mechanical drive units. If step mechanical loads can be applied to the unit, follow the generator set procedure with load steps.

Generator Set

The preferred adjustment procedure uses an artificial load bank. Use a utility or other sufficient capacity bus for a load only if a load bank is not available.

1. Apply a 25% to 50% step load to the generator, but avoid load-on steps that require significant time for the turbocharger to come up. This is best done with an artificial load bank, but plant loads such as compressor or fan motors may be started. If step loads cannot be obtained, use the procedure for mechanical drive units. Observe the off speed and recovery time performance when load is applied and dropped.

2. If excessive rapid but damped oscillations occur on load-off, reduce the **GAIN** set point slightly (25%).

3. If slow but damped oscillations occur on load-off, increase the **RESET** slightly. Increase the **GAIN** until the engine just begins to hunt and then reduce to 50% of that value.

   If speed slowly recovers on load-off, decrease the **RESET** slightly. Increase the **GAIN** until the engine just begins to hunt and then reduce to 50% of that value.

4. Set **COMPENSATION** to 25% of the **RESET** value and repeat steps 2 and 3 if desired.

5. Reduce **COMPENSATION** to 20% of **RESET**. Repeat the load steps and adjust **GAIN** as in steps 2 and 3 above. If control performance improves, leave **COMPENSATION** at 20% of **RESET**. If control performance degrades, increase **COMPENSATION** to 30% of **RESET** and readjust **GAIN** as in steps 2 and 3 above. If control performance improves, use the 30% value. If performance degrades or actuator movement is excessive, reduce **COMPENSATION** to 20—25% of **RESET**.

IMPORTANT

The final value of COMPENSATION should normally be 20—30% of RESET. Satisfactory performance may be obtained with other values in certain systems. Values lower than 20% may require an increase in RESET and a decrease in GAIN from values obtained at 25%. A value of COMPENSATION greater than 30% will require a reduction in RESET.

6. Operate the generator set throughout its operating range and conditions. If excessive high speed but damped oscillations occur on load dumps, it may be desirable to reduce the **GAIN** setting.

7. If the above dynamic settings were performed on a isolated unit and the generator will be paralleled with a utility bus, duplicate the dynamic settings in the second set with the exception of setting **GAIN** to 50% of the value determined in steps 2 through 5 above. Parallel the generator to the utility and operate the generator set throughout its load range to verify correct performance.

Mechanical Drive

1. Vary engine speed or load through the operating range of the engine and observe the performance.

2. During speed or load changes, if engine speed lags excessively behind the speed reference when it is changed, or off speeds are excessive when changing load, increase the **GAIN** set point. If fast hunting occurs, decrease the **GAIN** set point to 50% less than the value where hunting begins and increase **RESET** by 50%.

   During speed or load changes, if engine speed is observed to slowly oscillate in speed, decrease **GAIN** by 50% and increase the **RESET** by 50%.

3. Set **COMPENSATION** to 25% of **RESET**. If actuator movement is excessive, **COMPENSATION** may be reduced to lower values. For gas fueled engines, **GAIN RATIO** and **WINDOW WIDTH** adjustments may reduce actuator movement to acceptable levels without reducing **COMPENSATION** below the 25% of RESET level.

IMPORTANT	**In some cases, particularly if some slow process is being controlled, it may be necessary to reduce the ACTUATOR COMPENSATION value to zero. This could result in a under-damped system where some engine instability may occur, but may be required for satisfactory control of the process.**

4. Repeat steps 1 through 3 until you are satisfied with engine performance.

5. Continue with the additional adjustments below.

Additional Adjustments

After completing the above procedures, you can get improved control performance by adjusting **GAIN BREAKPOINT, GAIN SLOPE, GAIN RATIO**, and **WINDOW WIDTH**.

Gain Slope

1. Set **GAIN BREAKPOINT** equal to the control output an no-load. Alternately, an optimum value of **GAIN** at 0%, 20%, 40%, 60%, 80%, and 100% loads may be determined. Apply load for each step and increase **GAIN** until the engine begins to hunt, then reduce **GAIN** to 50% of the value where hunting begin. Record the value of **GAIN** and **ACTUATOR OUTPUT** for each point. Plot the values of **GAIN** vs **ACTUATOR OUTPUT**. If **GAIN** remains relatively constant up to a particular **ACTUATOR OUTPUT** value and then starts increasing, set **GAIN BREAKPOINT** equal to that value. If **GAIN** increases somewhat linearly with load, set **GAIN BREAKPOINT** at the no-load level.

2. Restore **GAIN** to the optimum no-load setting. Increase load to near 80%. Slowly increase **GAIN SLOPE** until the engine begins to hunt. Reduce **GAIN SLOPE** until the engine is again stable.

3. Operate the unit through its full load range. If instability occurs at some intermediate load, reduce **GAIN SLOPE** to obtain stable control.

Gain Ratio

In general, **GAIN RATIO** provides the greatest control improvement on gas fueled engines. A useful final **GAIN RATIO** of 10.0 or more can often be obtained on gas engines. Diesel engines can seldom take advantage of values over 2.0. The following procedure is for gas and diesel fueled engines, but directed specifically to gas engines.

1. Verify **WINDOW WIDTH** is set to 3% of **RATED SPEED**. Smaller values will typically result in the control remaining outside the window due to the anticipatory nature of the window.

2. Reduce **GAIN** to 50% of its current value and double the **GAIN RATIO**.

3. Perform speed or load changes to the unit. If instability occurs, reduce **GAIN RATIO** until stability is obtained and continue with step 4. If control remained stable, increase **GAIN** by 50%. If control continues to remain stable, repeat steps 2 and 3. If control becomes unstable, reduce gain by 50% and repeat steps 2 and 3.

4. Watch actuator movement while the engine is at steady state. Actuator movement should be minimal. If the actuator only occasionally “jumps” due to erratic cylinder combustion (indicating the control is operating at the higher gain outside the window), **WINDOW WIDTH** is at the optimum value. If excessive fast actuator movement occurs, slowly increase **WINDOW WIDTH** until only occasional jumps are observed. If **WINDOW WIDTH** is changed, repeat steps 2 and 3 above.

Be sure to save any changed set points before removing power from the control.

NOTICE	**To prevent possible damage to the engine resulting from improper control settings, make sure you save the set points before removing power from the control. Failure to save the set points before removing power from the control causes them to revert to the previously saved settings.**

We appreciate your comments about the content of our publications.

Send comments to: icinfo@woodward.com

Please reference publication 01304A.

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