Comdyna Model GP-6 Analog Computer, Serial Number 794

I. Bare-bones operating instructions

These instructions are for the user who has knowledge of the basic functioning of an electronic differential analyzer (more commonly known as "analog computer") for solving time-dependent ordinary differential equations (ODEs), and would like to start using this GP-6 without having to slog through the Operator's and Maintenance Manual. (I've used differential analyzers since the 1960s and Comdyna GP-6 and GP-10s since the mid 1980s, yet I still can't decipher some of the details in that manual.)

In accordance with the note on Figure 1-1, page 1 of the Operator's and Maintenance ("User") Manual, I placed a jumper across rear (back plane) terminals OP INPUT and OP OUTPUT, for operating this GP-6 alone, without any other GP-6s slaved to it. Also, I've never figured out what the SW receptacles of the integrating amplifiers on the patch panel are supposed to do, so I always place a jumper between the adjacent SW and OP receptacles (Operator's and Maintenance Manual, page 12); this works for my applications, and I don't ask why.

Either before or after you apply power to the GP-6, you may wire up ("program") your ODEs on the patch panel, connect to the patch panel an external input instrument such as a function generator or switched battery, and connect from the patch panel to an external display instrument such as an oscilloscope. Be aware, though, that when you plug-in or remove wires with power on, the GP-6 is electrically live; in particular the + and − (±10 V) receptacles are hot.

1. Connect the GP-6 to 110-V AC electricity with a power cord plugged into the receptacle in the back plane of the blue case.

2. Turn on the GP-6 by turning CW the COMPUTE TIME rotary switch/dial (on the operator panel) until it clicks. (I don't turn that dial any farther CW, because I don't know what else the COMPUTE TIME dial [a variable resistor] will do. I run ODE solutions mainly in real time, so I don't compress or expand the time scale, which the GP-6 is apparently capable of doing.)

The following steps 3 and 4 are with the X ADDRESS rotary switch (on the operator panel) in an unknown functional position. This is supposed to be an 11-position switch, but the lubricant on it has apparently dried up and hardened. Consequently, the switch is very difficult to rotate, and the positions no longer click, as they do on the Y/POT ADDRESS and MODE SELECTOR rotary switches. The X ADDRESS rotary switch position that I set unintentionally in the process of evaluating this GP-6 apparently does not interfere with any other standard functions of the GP-6. It is a sleeping dog that I decided not to rouse. Unless you are prepared to repair the X ADDRESS rotary switch, I recommend that you also leave it alone. I'll bet the switch can be repaired or replaced by a person with patience and circuit-soldering skill.

3. If your ODEs are patched onto the patch panel, you now may enter the coefficient potentiometer ("pot", a variable resistor) values. Position the MODE SELECTOR rotary switch to POT SET, and depress the IC mode control push button.

> a. Position the Y/POT ADDRESS rotary switch to the number of the pot that you wish to set, and the digital voltmeter display (DVM) will show the current value of that pot ($0 <$ value < 1).

> b. Rotate the knob (dial) of that pot CW or CCW until you set the value on the DVM that you want for the pot.

Repeat steps a. and b. for each pot that your ODE patching requires.

4. When your ODEs are programmed on the patch panel, and your coefficient values are all entered, and your external input and display instruments are connected, you may run the GP-6 to solve the time-dependent ODEs. With the IC mode control push button still depressed, position the MODE SELECTOR rotary switch to OPR; the ODE system is now in its initial condition (IC).

> a. Next, depress the OP mode control push button; this actuates the electronic, real-time, continuous (analog, as opposed to digital) solution of your ODEs.

> b. To stop the solution (for example, when all dependent variables have reached steady-state voltage values (-10 V $<$ value $< +10$ V, the overload limits), assuming your ODEs are stable), depress the IC mode control push button; this re-sets your ODE system to its initial condition.

Repeat the execution of the ODE solution as many times as you wish by depressing the IC and OP mode control push buttons.

II. Condition of GP-6, Serial Number 794

This GP-6 appears to be in very good operating and cosmetic condition. I have inspected it and played with its functioning for 3-4 hours. I'm not an electronics technician, and I haven't tested all possible functions, but I've given it a pretty good workout. The main thing I find that is not functioning as if SN 794 were new is the X ADDRESS rotary switch (on the operator panel), as described under paragraph I.2 above.

A standard GP-6 has two multiplier networks. However, SN 794 appears to have four, with the patch panel receptacles of the non-standard two positioned to the left and right of inverting amplifiers 7 and 8 at the bottom of the panel. And there are two dual-multiplier circuit boards, one (labeled 983) mounted on the backside of the patch panel, the other (labeled 982-1) mounted on the bottom surface inside the GP-6 blue case. (You can look inside the blue case and at the backside of the patch panel by loosening the two thumb screws near the top edge of the panel, then rotating the panel forward about hinges

on the bottom edge.) Appearances can be deceptive, though, and only two of the apparent four multiplier networks function properly—see section IV below.

All of the circuitry inside the blue case appears to be clean and functional. Two of the original-equipment small yellow precision capacitors (apparently associated with integrating amplifiers 1 and 2) were replaced, probably by a previous user, with much larger silver capacitors. I haven't detected any differences between the functioning of integrating amplifiers 1 and 2 and the functioning of integrating amplifiers 3 and 4, which apparently have all of the original precision capacitors. But the replacement capacitors might be associated with time scaling, which I did not test.

III. Example solution of ODEs on SN 794

I show here an approach for solving by analog computing the standard 2nd order vibration ODE (from most basic linear-systems and vibrations textbooks), which is

$$\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n{}^2 x = \omega_n{}^2 u \ .$$

In this ODE, $u(t)$ is a time-dependent input or forcing function, time t in seconds being the independent variable, $x(t)$ is the output function, ω_n is the undamped natural frequency of vibration in radians/sec, and ζ is the viscous damping ratio. Possible initial conditions (at time $t = 0$) are $\dot{x}(0) \equiv \dot{x}_0$ and $x(0) \equiv x_0$. In the analog-computer implementation here, $u(t)$ is a driving voltage (say, from a function generator or a switched battery), and $x(t)$ is a response voltage. It is appropriate for the analog-computer programming that follows to rewrite the ODE in the form

$$\frac{d(\dot{x}/\omega_n)}{dt} = -\left[-\omega_n u + 2\zeta\omega_n(\dot{x}/\omega_n) + \omega_n x\right]$$

Figure 1 below is a somewhat general analog-computer block diagram for solving this ODE, provided that $0 < \omega_n \leq 100$ rad/sec and $0 < \zeta \leq 0.05$. These limits apply because the maximum standard input gain constant G for a GP-6 integrating amplifier is 100.
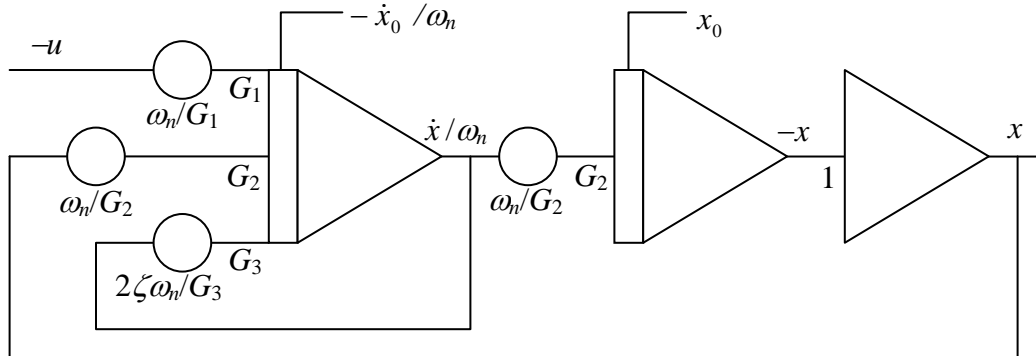

Figure 1

   Two implementations of the circuit in Figure 1 are shown wired on the SN 794 patch panel in the photograph Figure 2 below.
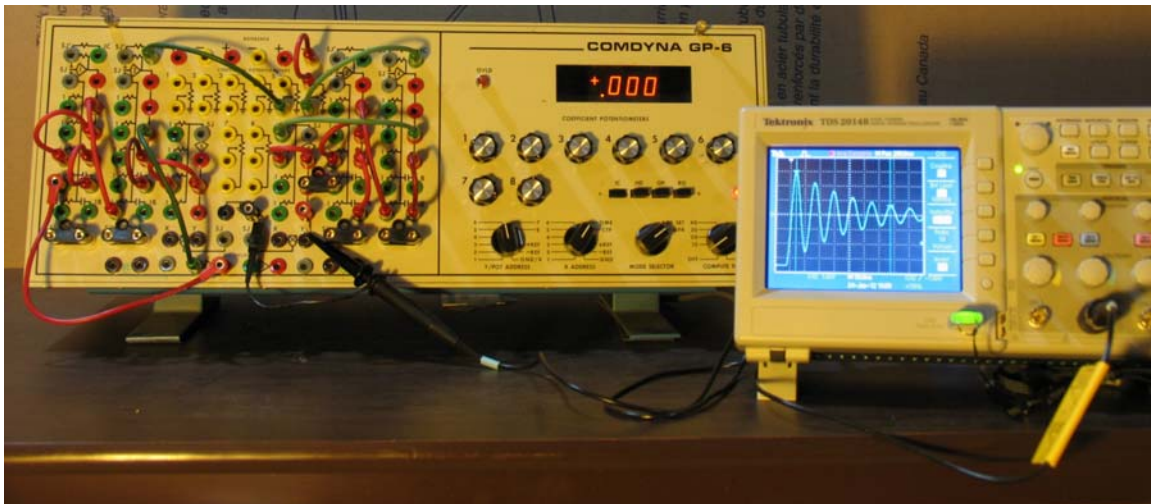

Figure 2

   The ODE solution shown on the screen of the digital oscilloscope in Figure 2 is the voltage output x of amplifier 6 that resulted from operating the particular circuit in Figure 3 below, with only an initial-condition $x_0 = -3.50$ V applied onto integrating amplifier 4 but no input u voltage. The coefficient pots at the inputs to the integrating amplifiers shown in Figure 1 are not present in Figure 3, or alternatively, you can think of them all as being set to the maximum value, 1.
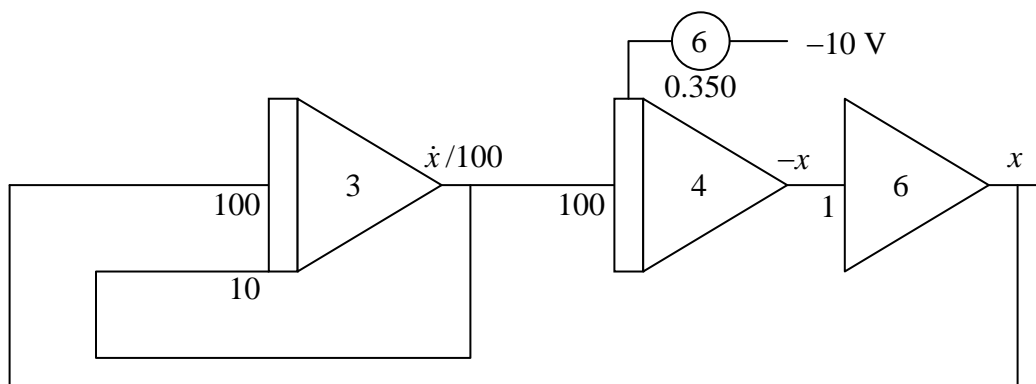

Figure 3

The oscilloscope trace in Figure 2 is shown in greater detail in Figure 4 below. Measurements on this record shows that the frequency of the signal is very close to the theoretically predicted value, $f_n = \omega_n/2\pi = 100/2\pi = 15.9$ Hz, and the damping ratio also is very close to the theoretically predicted value, $\zeta = 0.05$.
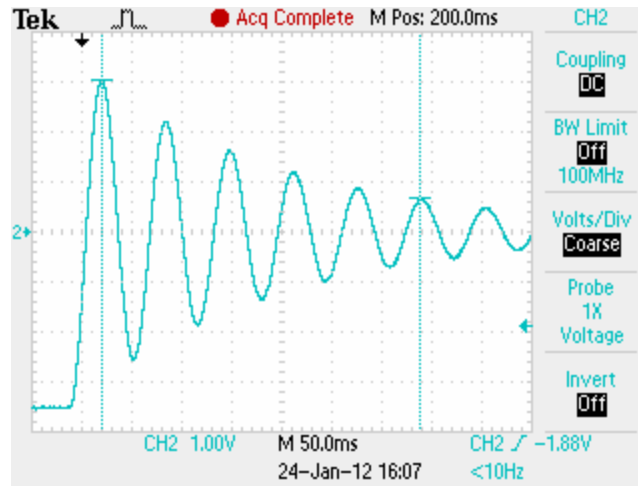
Figure 4

The analog-computer block diagram of the other circuit on the patch panel in Figure 2 is shown in Figure 5 below. This circuit is a factor of 10 slower than that in Figure 3.
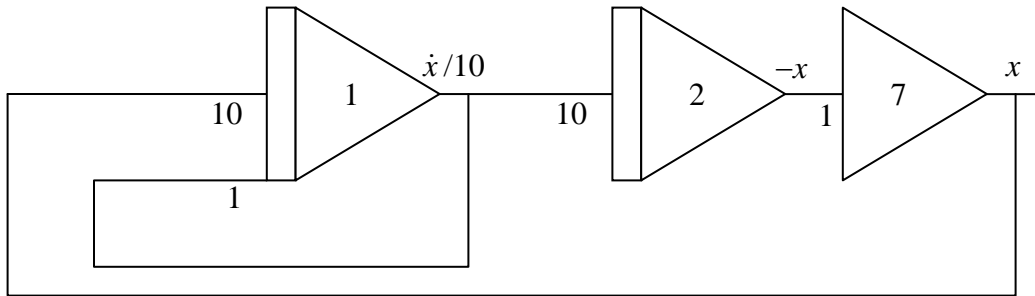

Figure 5

I tested this circuit also, with an initial condition voltage applied to integrating amplifier 2. I measured the frequency of the response signal to be very close to the theoretically predicted value, $f_n = \omega_n/2\pi = 10/2\pi$ = 1.59 Hz, and the damping ratio also to be very close to the theoretically predicted value, $\zeta = 0.05$.

In the process of testing this GP-6, I tried all eight amplifiers and all eight pots in the circuits of Figures 3 and 5. All of these components functioned nominally for this particular ODE solution.

Note on Figure 2 that summing amplifier 5 was unused in the circuits of Figures 3 and 5 shown in the photograph; but, even so, a jumper connects the output of summing amplifier 5 to its input with a feedback resistor. I've found that such feedback is required on unused amplifiers just to prevent them from drifting into overload any time the GP-6 is powered.

IV. Evaluation of the multiplier functions on SN 794

To test multiplier functioning, I programmed each trio of multiplier-network receptacles to multiply the outputs of the two separate circuits diagrammed on Figures 3 and 5 (but with the circuits modified to eliminate damping feedback by removal of the $2\zeta\omega_n/G_3$ feedback connection shown on Figure 1, so that each circuit was nominally an undamped oscillator). The SJ receptacle of a multiplier network must be connected to the SJ receptacle of a summing amplifier (Operator's and Maintenance Manual, page 13); I used the previously idle summing amplifier 5 for this, so the "product" of the two oscillator signals was the output of summing amplifier 5. Contrary to what is printed on page 13 of the Operator's and Maintenance Manual, the actual multiplier output signal is the negative product of the two input signals <u>divided by 10</u>, i.e., $\mathbf{E_O = -(A \times B) \div 10}$, not just $\mathbf{E_O = -(A \times B)}$.

Figure 6 is the digital-oscilloscope screen image of signals from a run using the left-side non-standard multiplier network. (See the second paragraph of section II for the meaning of "left-side non-standard".)
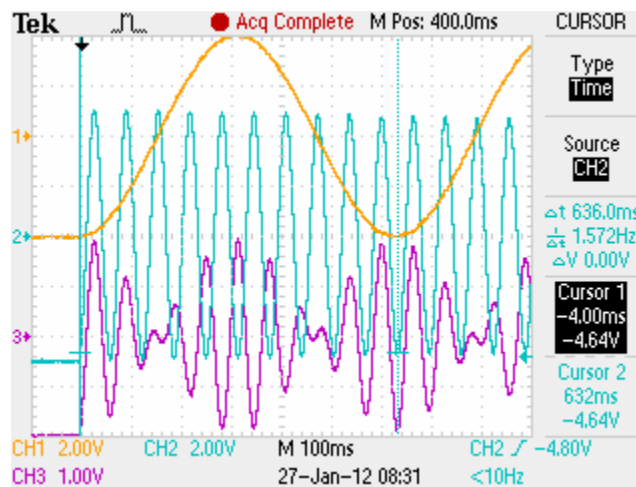

Figure 6

In Figure 6, the output of summing amplifier 6 (in Figure 3), the yellow signal, was a 1.57-Hz, 4-V peak-to-peak sinusoid; the output of summing amplifier 7 (in Figure 5), the cyan signal, was a 15.7-Hz, 5-V peak-to-peak sinusoid; and the output of summing amplifier 5 (functioning with the left-side non-standard multiplier network), the purple signal, was one-tenth the negative product of the two sinusoids, a modulated signal of maximum amplitude 2-V peak-to-peak.

I tested also the right-side non-standard multiplier network, and it also functioned correctly. However, the two multiplier networks with receptacles in the standard positions on the patch panel, just above summing amplifiers 7 and 8, did <u>not</u> function correctly. For each, when the SJ receptacle of the multiplier network was connected to the SJ receptacle of summing amplifier 5, the amplifier immediately overloaded. The

Operator's and Maintenance Manual, page A11, recommends adjustments for 982.2 and 983 multiplier-network circuit boards. But I didn't take the time to fiddle with adjustments or conduct troubleshooting. It is difficult to track visually the circuitry inside SN 794, but my <u>guess</u> (no more than that) is that the two functional multipliers are on board 983, and the two non-functional multipliers are on the lower-numbered and probably obsolete board 982-1. My further <u>guess</u> is that Comdyna originally assembled SN 794 with board 982-1. But then they might have discovered that board 982-1 was defective and retrofitted SN 794 with board 983 pre-sale, without removing board 982-1. Perhaps Comdyna just instructed the original purchaser not to use the multiplier-network receptacles that are connected to board 982-1. Or perhaps Comdyna installed board 983 post-sale when the original purchaser determined that the multipliers on board 982-1were defective and returned SN 794 to the Comdyna factory for repair under the warranty. Just as for most used instrumentation, the original paperwork for SN 794, including the specific user's manual/instructions and any calibrations associated with SN 794, has long since disappeared.