

SP4 DOCUMENTATION

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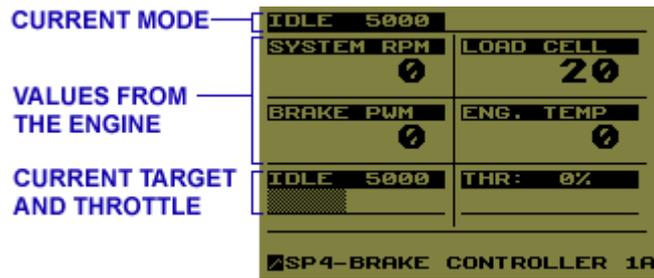
1. SP4 Reference manual.

The SP4 system consists on a console + one controller module to automate all functions on a dyno room (engine room) or a vehicle dynamometer. It has certain inputs and outputs to acquire data from the engine and to control the brake and other parts of the installation. Connections are explained below:



1.1. SP4 console.

- **Display:** 192x128 pixel LCD display:



First line shows the current mode.

Central area, current values read from the engine. By default: “System Rpm” (calculated using brake rpm and ratio), Load Cell (N*m), Brake PWM (current output from 0 to 1023), Engine Temp (from channel A). These values could be configured in next versions.

Lower area show current value (for example for Steady RPM, it will shown then target RPM), and throttle position (%)

- **Right knob**, throttle handle. It changes the throttle position directly.
- **Left knob**, value. Depending on the current mode it will change the current value:
 1. Steady RPM: rpm target (rpm)
 2. RPM RAMP: ramp value (rpm/sec)
 3. BRAKE MODE: brake action (n/1023)
 4. Configuration Menu: current value
- **Buttons (divided into three groups):**
 1. **First and second column** control the 8 outputs: ignition, starter, fan1 and fan2, and 4 extra functions.
Each time one of these buttons is pressed its value changes from On-Off or backwards.
 - **Ignition relay** is used to control the ignition current for the engine. It is useful to stop the engine at any time from the SP4 module.
 - **Starter relay** is used to activate the starter motor to run the engine. This button is different, it is ON while the button is pressed, but when it is released it turns OFF automatically.
 - **Fan1 and Fan2** are used to control ventilation and cooling inside the dyno room. They may be connected as you want.
 2. **3rd and 4th Columns**, working mode: idle, steady rpm, ramp, brake, start/stop, throttle.
 - **Idle**: brake output=0, throttle output=default (0). In this mode you can change the target rpm so the value is ready to change to the “Steady Rpm” mode, but it has no action over the engine yet.
Steady Rpm: Before entering this mode it is useful to set the target value in the idle mode. Once the button is pressed, the mode is activated and the PID is used to calculate brake output all time to keep the engine at the desired target value. You can change the load (throttle) to tune the engine. If load is changed suddenly the PID won't keep the engine at the desired value for a while. But it quickly will adjust the brake action to reach the desired value, depending on the PID values.
 - **RPM ramp**: This mode is used to do a dyno run with a determined acceleration. If a test starts at 3000 rpm and ends at 6000 rpm with an acceleration of 100 rpm/s, it will take 30 seconds to be done.
As the test duration is longer the accuracy increases because the effect of the inertia over the readings is lower and engine works more stable.
The way to start a RPM ramp is from “Steady Rpm” mode, with the engine stabilized at the desired starting value. If the test is started directly in RPM ramp and throttle is open quickly, the PID will take some time to stabilize

the engine rpm at the beginning of the dyno run, and it won't be useful at all, because the first part of the test won't be as desired.

- **Retarder:** Not yet implemented. It uses a fixed table with brake values vs. rpm to control the brake. It may be useful to control a hydraulic brake.
- **Brake Test:** It applies the selected value to the brake. With the left knob the user can change the value applied to the brake. It may be useful to check the brake, but not to do dyno runs. **Note:** the value defined in this field has not to be the actual value applied in the PWM box, because the system uses a correction factor called "brake offset" to linealize the power supply output, for example, in our power supply we use a value of 130, this means that brake pwm will be: 0, 130, 131, 132, and so on...
- **Unused:** the 6th button is not used yet.
- **Start/Stop:** this button is used to start/stop the data recording in the SportDyno software. It has the same effect as the button from the controller.

MAX THROTTLE: this button will alternate between closed throttle and open throttle. If the throttle is completely closed (0%) it will apply the full throttle value (99%) (the user can then change to the desired value, for example to 90%). If the throttle is not closed (from 90%, for example) it will always go to closed position (0%), if the user press the button again, the system will return to the previous position (90%). This button is very useful to test transients in the engine as a quick way to open the throttle, and a safe way to close it quickly (idle button does the same action)

3. MENU Buttons.

- 1- **Up/Down**, are used to move between the menu options, by clicking one of them from the main screen enters in the menu mode.
- 2- **Select**, by pressing select the program enter in the option selected in the menu. If pressed from the main screen, it enters in the menu mode.
- 3- **Back**, It returns from the current option. If pressed in the main screen it has no effect.

1.2. Configuration:



- **PID configuration:** These values are used to control the engine RPM at Steady RPM and RPM Ramp modes. **KP**-proportional, **TI**-Integral, **TD**-derivative. They can be changed with the left knob. Its performing is explained later.



Ramp min, and max values are also in this window, these values are used in the ramp mode as limits to the ramp auto-increment. When the engine decreases its speed (because throttle is closed) the system detects this condition and decreases automatically the target rpm, this value is limited by the “ramp min” value. When the engine is accelerating, the target value is increased automatically at the ramp rate until the “ramp max” value is reached.

- **Throttle(s) configuration.**

Note: These options are **ONLY** available when the engine is **OFF** (relay0=OFF).

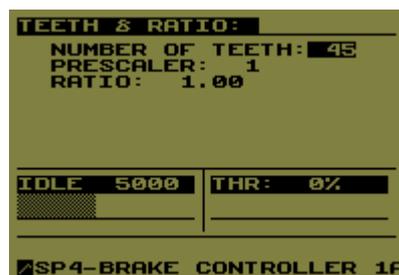


MIN THROTTLE: starting position for the servo when THR=0%. In steps of 1/255. You have to ensure the throttle is completely closed at this position (consider engine's idle adjust). In this option both knobs can be used to change the value.

MAX THROTTLE: ending position for the servo when THR=99%. In steps of 1/255. You have to ensure the throttle is completely open at this position. In this option both knobs can be used to change the value.

Note: MIN THR can be greater than MAX THR if you want the throttle servo runs in opposite direction.

- **TEETH and RATIO:**



Note: Although these options are available with engine running, **it is recommended to operate them only with IDLE MODE activated** (because they affect to the PID and brake operation).

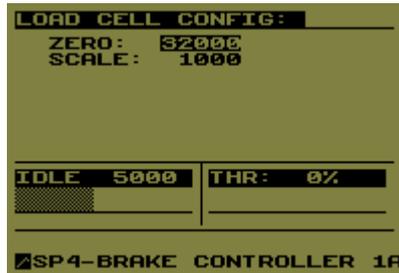
Teeth: number of teeth of the sprocket. By using the left knob this value can be changed.

Prescaler: depending on the number of teeth, you will select between 1, 4 and 16. Usually prescaler=1 is used for number of teeth lower than 16. Prescaler=4 for 16 to 64. And prescaler=16 for higher number of teeth.

RATIO: Ratio between engine and brake. All rpm values on the SP4 are referred to the engine, but they are measured on the brake, thus this value is very important for the SP4 performing.

A first test with the engine RPM channel is needed to find the ratio value before starting to work with SP4.

- **LOAD CELL:** This window is used to setup the values related with the load cell displaying. The load cell data is transmitted directly to the computer, and these values are not used for the data received, only for the displaying in N*m units in the SP4 screen.



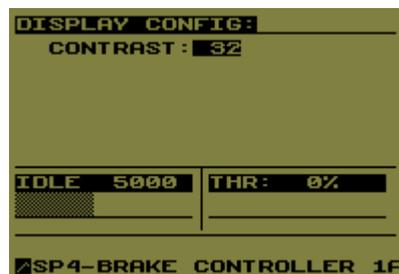
Zero: this value is subtracted to the load cell channel to make the zero in the reading, positive values are used for pulling forces on the cell, and negative values for pushing forces on the cell. For example if the raw data is 33000, the zeroed reading will be: $33000 - 32000 = 1000$.

Scale: this value is multiplied by the load cell channel and divided by 65536 to get the actual reading in N*m units. For example if the load cell channel is 300 (after subtract zero), then the reading will be: $300 * 1000 / 65536 = 4.57 \text{ N*m}$

- **Brake offset:** brake's power supply is not linear. It starts to provide current with brake values higher than 130 (130/1023), but it may change depending on the country's mains frequency. This value is added to the brake action (when it is higher than 0) to get a suitable control signal over the power supply.



- **Contrast** of the LCD display, values lower than 32 makes a weak displaying, and values higher than 32 makes a dark background.

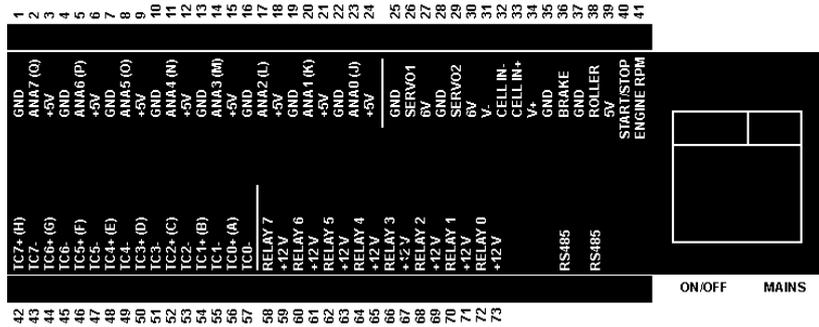


- **Channels,** this window shows the current raw data from the channels acquired from the engine.



1.2. SP4 I/O module.

SP4 I/O MODULE



1. Analog inputs. Sensors from 0 to 5 volt (pins 1-24)

1	GND	13	GND
2	Analog input 7 (key Q)	14	Analog input 3 (key M)
3	5 Volt	15	5 Volt
4	GND	16	GND
5	Analog input 6 (key P)	17	Analog input 2 (key L)
6	5 Volt	18	5 Volt
7	GND	19	GND
8	Analog input 5 (key O)	20	Analog input 1 (key K)
9	5 Volt	21	5 Volt
10	GND	22	GND
11	Analog input 4 (key N)	23	Analog input 0 (key J)
12	5 Volt	24	5 Volt

2. Servos. This output can control a high torque RC servo to drive the throttle. Output specs: pulse 0.5 ms – 1.5 ms, frequency 50 Hz.

25	GND	28	GND
26	Servo 1 (Throttle)	29	Servo 2
27	6 Volt (3 Amp)	30	6 Volt (3 Amp)

3. Load cell, direct connection from load cell, internal 16 bits amplifier.

31	V- (gnd)	33	Cell IN +
32	Cell IN -	34	V+ (5 volt, regulated)

4. Brake output. This output is a PWM output at 14 KHz that goes from 0 to 5 volt in steps of 5/1023 volt (~5mv). At full output (brake=1023), the brake's supply will output aprox. 190 volt. When connecting the brake's supply to a 96 volt brake it will be needed to reduce its range with an external potentiometer (10K).

35	GND	36	Brake Output
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5. **Roller input.** Roller/Brake RPM input. Usually a Hall effect sensor and a sprocket are used to read brake speed.

37	GND	39	5 volt
38	RPM in (active HIGH)		

6. **Start/Stop Button.** This button can control from this unit the SportDyno program operation. It is activated when connected to ground.

40	Start/Stop (active LOW)
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7. **Engine RPM.** This input is sensitive to small current pulses, it can be used with the capacitive clamp or with inductive one (with an adaptor).

41	Engine RPM (current pulses)
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8. **Thermocouples.** Eight thermocouples type K (upto 1000 °) can be connected to the I/O module.

42	TC7 + (key H)	50	TC3 + (key D)
43	TC7 -	51	TC3 -
44	TC6 + (key G)	52	TC2 + (key C)
45	TC 6 -	53	TC2 -
46	TC5 + (key F)	54	TC1 + (key B)
47	TC5 -	55	TC1 -
48	TC4 + (key E)	56	TC0 + (key A)
49	TC4 -	57	TC0 -

9. **Relays.** Eight 12 volt relays can be connected to the I/O module. Ignition and starter have a fixed function in the system.

58	Relay 7	66	Relay 3 (fan 2)
59	12 volt	67	12 Volt
60	Relay 6	68	Relay 2 (fan 1)
61	12 Volt	69	12 Volt
62	Relay 5	70	Relay 1 (Starter)
63	12 Volt	71	12 Volt
64	Relay 4	72	Relay 0 (Ignition)
65	12 Volt	73	12 Volt

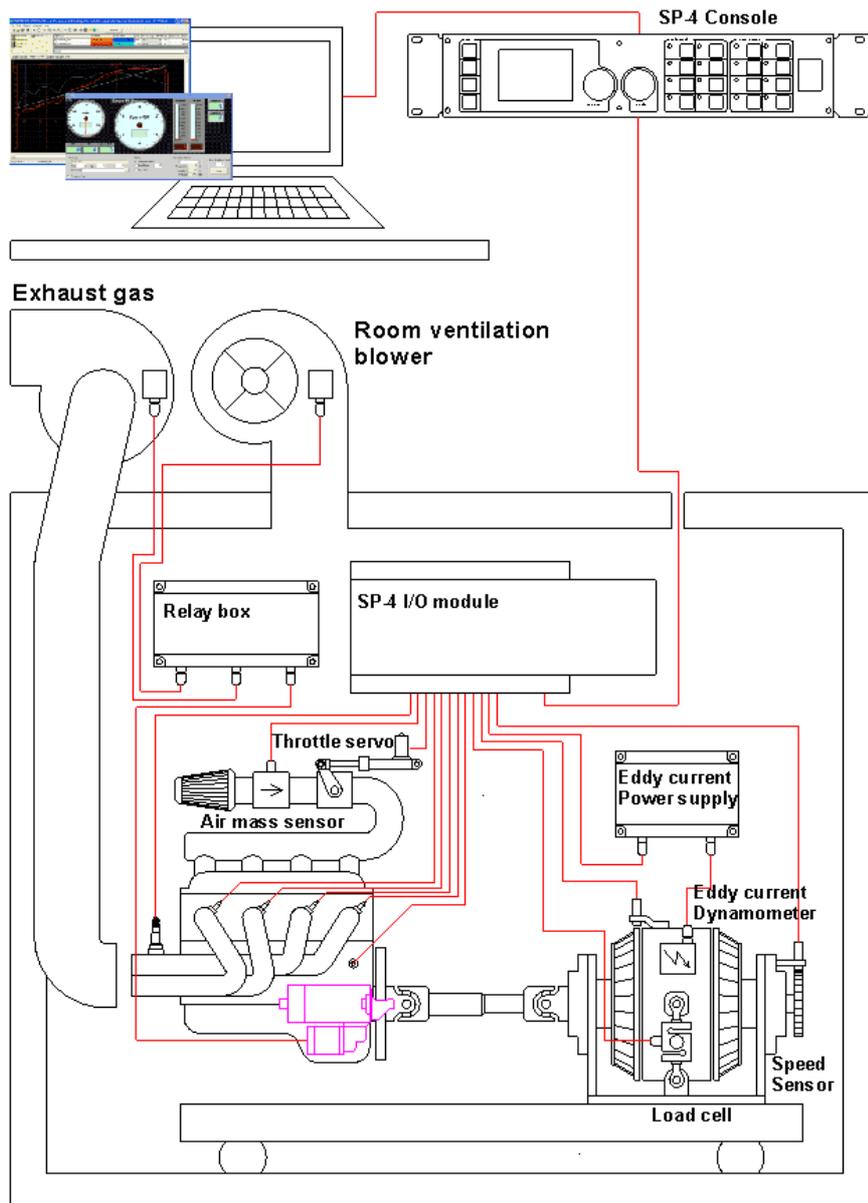
10. **RS485.** Two connectors, from controller to console, both are the same. **Don't connect here an Ethernet computer network! This connector has 15 volt and will damage the Ethernet card!**

11. **Mains.** 230 Volt, 50/60 Hz

2. Dynamometer Installation.

SP4 is designed to control most parameters of the engine, and to enable the user to operate the engine outside the dyno room to work safe and comfortably.

Below is shown a typical dyno room controlled with SP4:



2.1. Installation parts.

- **SP4 console and I/O module.** They can work stand alone or with the computer. Obviously the computer will be needed to do data acquisition.
- **Computer.** Pentium II or higher, Win98, ME, 2000 or XP.
- **Hall Effect Sensor.** It reads brake speed.
- **Gear Tooth.** Installed on the eddy current brake to read its speed. For example 8 teeth.
- **Load Cell.** It depends on the engine, typical values are 450 kg for motorcycle engines and 1000 kg for cars, but it should be calculated.
- **Load Cell Amplifier.** SP4-rev.a uses an external amplifier for load cell.
- **Eddy Current Brake.** 192 volt rated, it size depends on the application.
- **Power supply:** Semikron control module + SCR & diode pack.
- **Throttle Servo (optional).** A high torque RC servo is used to drive the throttle.
- **Ignition and Starter Relays.** 12 volt relays to control the engine. Additional relays can be installed on the SP4 to control the fans on the room.

- **Acquisition Modules (optional)** More modules will be available: weather station and engine timing acquisition (ignition pulse and position, injection pulse and position)
- **Fans / Turbines.** Some type of fans or turbines are needed to next functions:
 - Feed the air intake with fresh air from outside the room (air inside the room gets hot quickly) this turbine should be very high power (>2 KW, or >5KW) and high speed to simulate on-track conditions, a variable speed driver is recommended + frequency to voltage converter to use the air speed.
 - Exhaust extraction, the pipes should be made with iron or steel because the high temperature of exhaust gas.
 - Engine coolant, water should be cooled by a fan, a car's fan or a truck's fan can be used with a thermostat to ensure the water will be at a right temperature all the time.
 - Engine and exhaust pipes cooling, when running on the track the exhaust pipes are being cooled as the vehicle runs, but when working on the dyno they may get too hot and can be damaged. Sometimes certain exhaust pipes can not work at high temperatures (for example: titanium)
- **Variable speed driver.** It is recommended to control air-intake turbine.
- **Frequency to voltage converter.** It converts the brake speed to a voltage for the variable speed driver. Our F-V converter has a programmable transfer curve to let the user to adapt the turbine speed to the brake speed as he needs. It recommended installing one air speed sensor to monitor air speed.

2.2. Connectors and cabling.

At the rear of the SP4 box are placed the connectors:

1. Relays.

Pin 1: 12 volt,
 Pin 2: Relay1, ignition,
 Pin 3: Relay2, starter motor,
 Pin 4: Relay3, fan1, other applications,
 Pin 5: Relay4, fan2, other applications,
 Pin 6-9: reserved.

2. Load cell, prototype uses an external amplifier for the load cell:

Pin 1: load cell input (from amplifier),
 Pin 2: GND to amplifier,
 Pin 3: 10 Volt to amplifier.

3. RPM input. Brake RPM input. Usually a Hall effect sensor and a sprocket are used to read brake speed.

Pin 1: VCC, 5 volt,
 Pin 2: GND,
 Pin 3: RPM input, active high.

4. RS232. Connector to the computer. 115200 baud, no parity, 1 stop bit.

5. RS485. Connector to the SP4 network. **Don't connect here an Ethernet computer network! This connector has 15 volt and will damage the Ethernet card!**

6. Brake output. This output is a PWM output at 14 KHz that goes from 0 to 5 volt in steps of 5/1023 volt (~5mv). At full output (brake=1023), the brake's supply will output aprox. 190 volt. When connecting the brake's supply to a 96 volt brake it will be needed to reduce its range with an external potentiometer (10K).

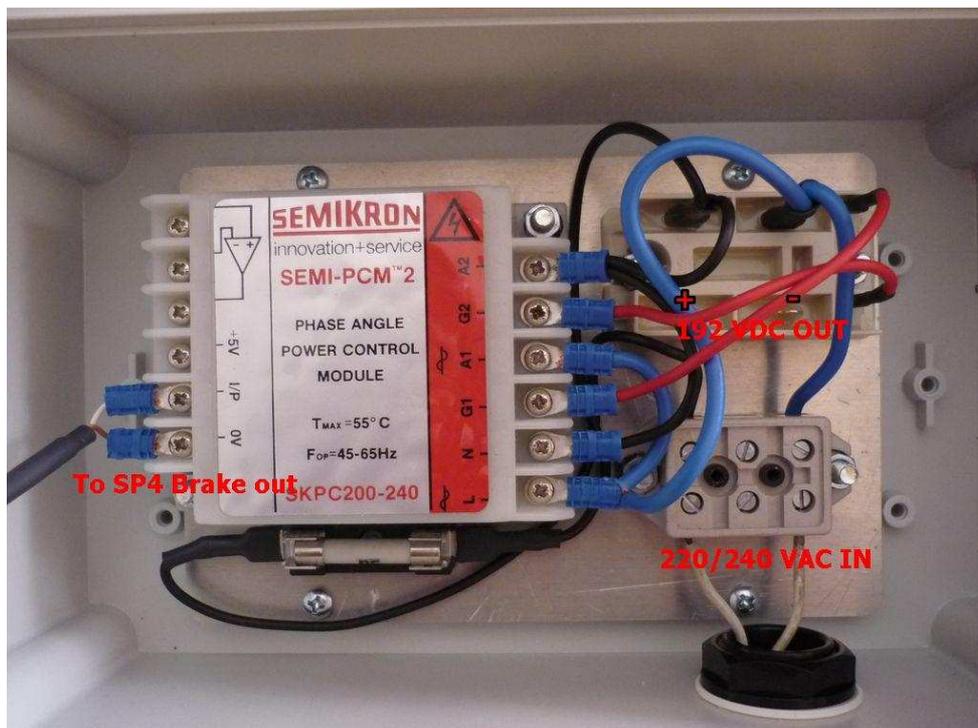
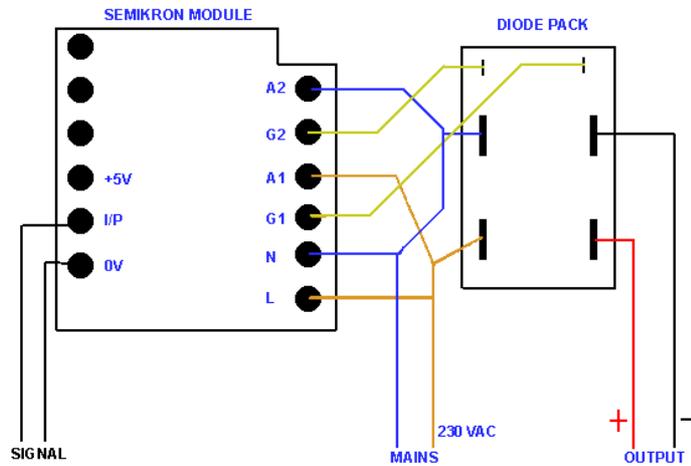
Pin 1, GND,
 Pin 2, not connected
 Pin 3, output.

7. **Servo output.** This output can control a high torque RC servo to drive the throttle. Output specs: pulse 0.5 ms – 1.5 ms, frequency 50 Hz.

Pin 1, GND
 Pin 2, 6 Volt, servo supply,
 Pin 3, pulse output.

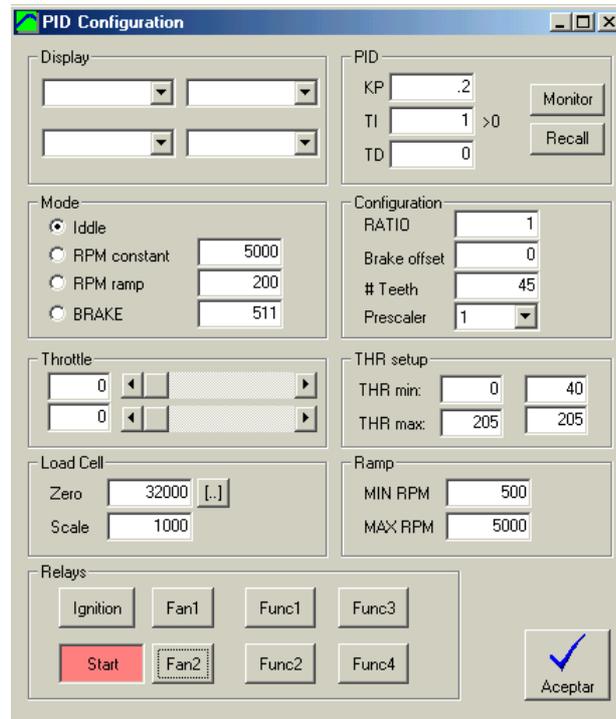
8. **POWER SUPPLY.** The power supply has one wire to the SP4 box, this wire is connected to the brake output connector, and it comes with its own connector. It has two wires (orange and cyan) that are connected to mains: 230 volt 50/60 Hz. This wires supply the brake through this device. It is recommended to place a fuse of the right amp value (default 20Amp). The supply has two more wires (black and red) that are the output, and are connected to the brake. The default brake is a 192 volt type, but a 96 volt type can be used if the range of the supply is limited by the internal potentiometer.

Supply internal diagram (30 amp SCR pack):



3. System setup.

System can be setup from the console of by using the SportDyno software (version 3.3 or higher)

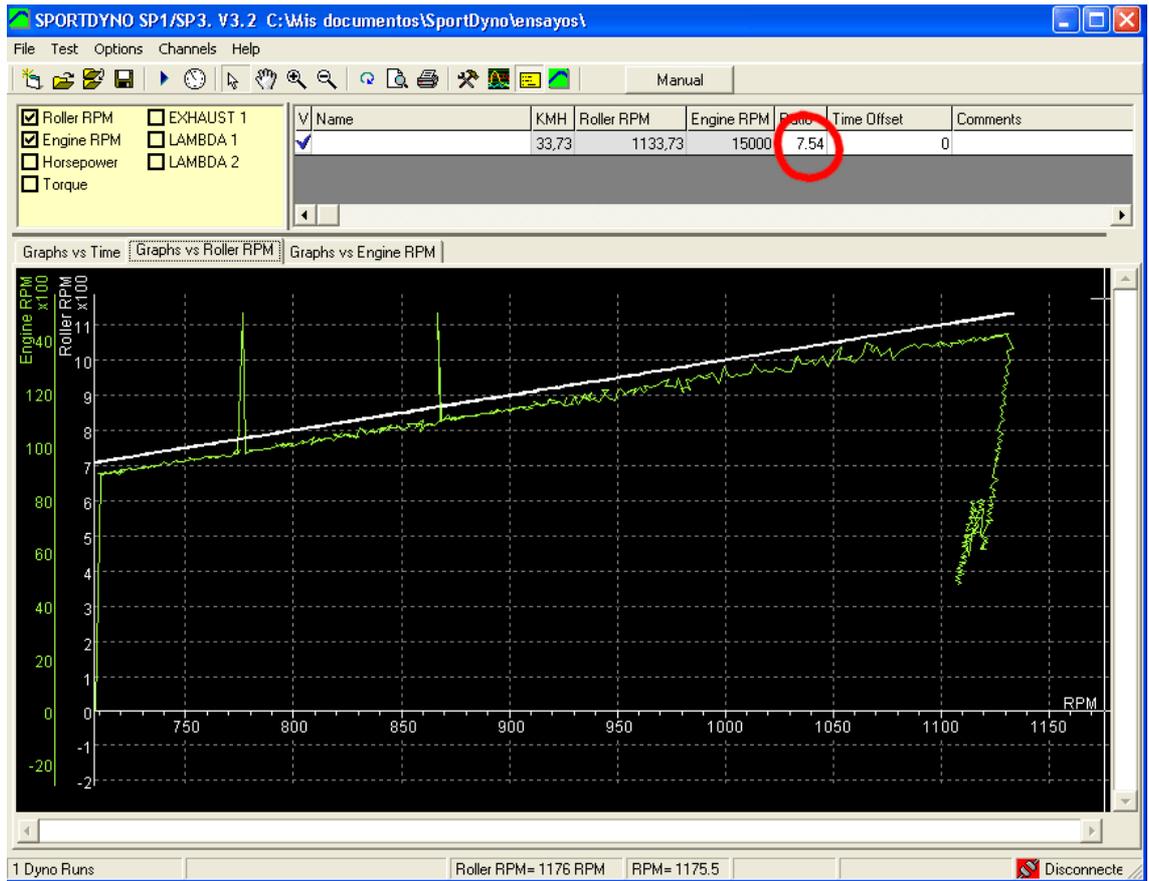


3.1. Ratio.

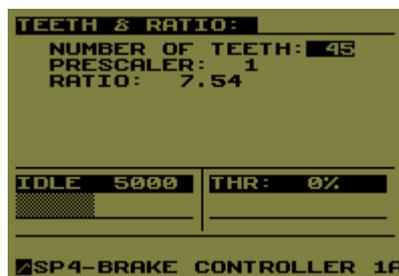
It is the ratio between engine and brake. All rpm values on the SP4 are referred to the engine, but they are measured on the brake, thus this value is very important for the SP4 performing.

The first SP4 version (prototype) has not engine rpm input, so a first test with a SP1 or SP3 module will be needed to find out the ratio value before starting to work with SP4.

Below is shown an example done with a SP1:



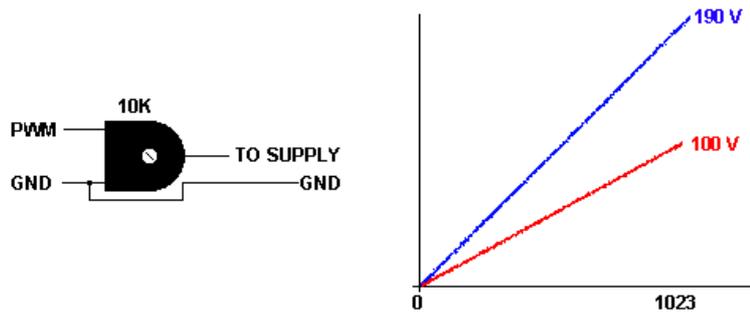
The ratio for this engine is 7.54; this value is input in the configuration with the right knob:



If the engine is connected directly to the brake (without a gearbox) the ratio will be 1.

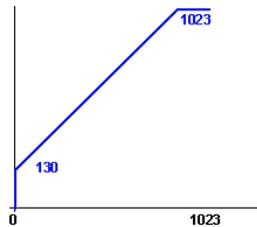
3.2. Brake.

Output range: at full output (brake=1023), the brake's supply will output aprox. 190 volt. When connecting the brake's supply to a 96 volt brake it will be needed to reduce its range with an external potentiometer (10K).



Brake offset: our brake's power supply is not linear. It starts to provide current with brake values higher than 130 (130/1023), but it may change depending on the mains frequency of your country.

This value is added to the brake action (when it is higher than 0) to get a suitable control signal over the power supply.



3.3. Throttle Servo.

A high torque RC servo can be used to drive the throttle.

In the configuration menu can be found these options:



MIN THROTTLE: starting position for the servo when THR=0%. In steps of 1/255. You have to ensure the throttle is completely closed at this position (consider engine's idle adjust). In this option the LEFT knob is used to change the value.

Note: This option is not available when the engine is running (relay1=ON).

MAX THROTTLE: ending position for the servo when THR=99%. You have to ensure the throttle is completely open at this position. In this option the LEFT knob is used to change the value.

Note: This option is not available when the engine is running, it will accelerate suddenly.

4. PID setup.

PID values are used to control the engine RPM at RPM-CTE and RPM-RAMP modes. P-proportional, I-Integral, D-derivative values are accessed by pressing several time this button, and then can be changed with the right knob.

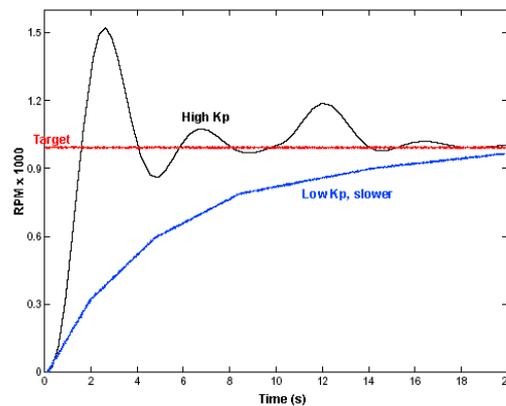
$$u(t) = K_p e(t) + \frac{K_p}{T_i} \int_0^t e(\tau) d\tau + K_p T_d \frac{de(t)}{dt}$$

The user can change the Kp, Ti and Td values. In other texts this values are referred as: Kp, Ki and Kd or simply: P, I, D.

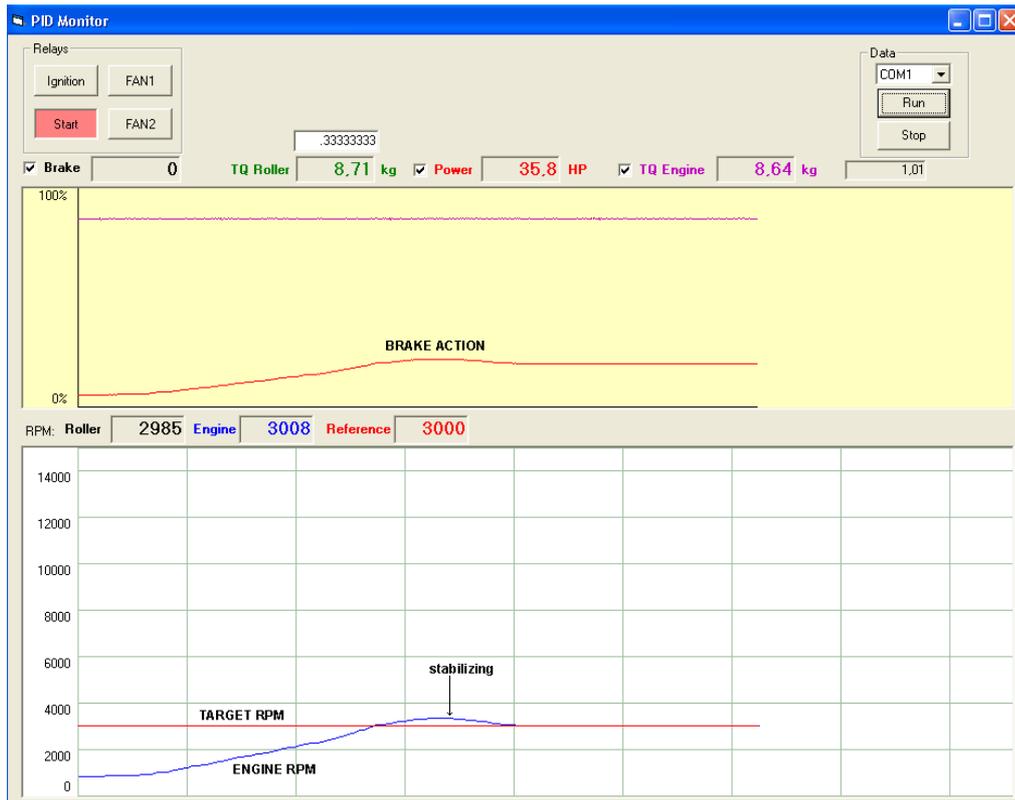
Basically a PID controller calculates the difference between the target value and the current one, this is called error $e(t)$, and uses it to generate a control action $u(t)$ over the system (to the brake).

It uses the Kp, Ti and Td values to get this output signal.

1. **Kp**, is the proportional coefficient, it makes the system faster but it will oscillate for big values. **The goal is to get a low Kp that makes the system works fine** in spite of being a bit slow, to avoid oscillations. If only using the Kp value the system won't reach the exact target value, this is called "position error", to remove this error is used the Ti value.



2. **Ti**, is the Integral time constant, it is used to avoid the "position error". It makes the system to reach slowly the target value when it is close to it. Small values makes the system reach the desired value faster, but it makes the system to be slower to changes and may cause big oscillations. **The goal is to get a high Ti value that makes the system works fine.**
3. **Td**, is the derivative time constant, it is used to make the brake to follow the engine changes quickly. It may compensate the delay introduced by the Ti value. It will be a match Td value that will work fine with certain Ti value. **The problem when using the Td coefficient is that introduces noise in the control signal** and in the load cell signal, and thus is not useful when acquiring the TQ and HP. **We set Td=0 in the initial configuration.**



5. Doing dyno runs

The SP4 controller can be used in several ways:

One of them is to keep the engine running at certain speed, and certain load (not always %) in order to be able to carburate the engine point by point for ECU setup (injection and ignition).

This can be done simply by using the “RPM constant” mode. This mode will keep the engine running at selected speed (after a little period of stabilization).

This process can be done at different loads, and then the controller will apply different signal level to the brake’s supply.

Another way is to use the ramp feature to do a standard dyno run to get the typical HP and TQ curve vs. rpm, as explained below.

5.1. Manual dyno control:

At the moment the user can operate over the SP4 console to make the dyno to change its state. The SP4 unit will control the speed and/or acceleration of the system depending on the selected mode.

- The first step before doing a dyno run is to warm the engine in the idle state. In this state, the SP4 lets the brake to run free. Thus, regardless of having a clutch (in engine dynamometers) the engine will run free
- The second step is to stabilize the system at certain speed in order the system gets a stable speed at full load. In “rpm constant” mode the user will accelerate to max progressively to let the system control the speed. In engine dynos this can be done by using the throttle control from the console (using the throttle servo), and on vehicle dynos this usually will be done directly by the operator.

- When the system is stable at the desired speed the test could be started: enter in ramp mode to let the engine start to accelerate and then **start data acquisition** on the SportDyno software.
- When test is finished (near the maximum rpm for such engine) the user will **stop data acquisition** on the program, and then will close the throttle (on the console or manually). At this moment, the controller will leave the brake free as the speed is lower than expected, and the system will slow down progressively.
- The user can enter in idle mode now. It is recommended to keep the brake running for a while in order it can dissipate all the heat it has got during the test.

5.2. Automated dyno control:

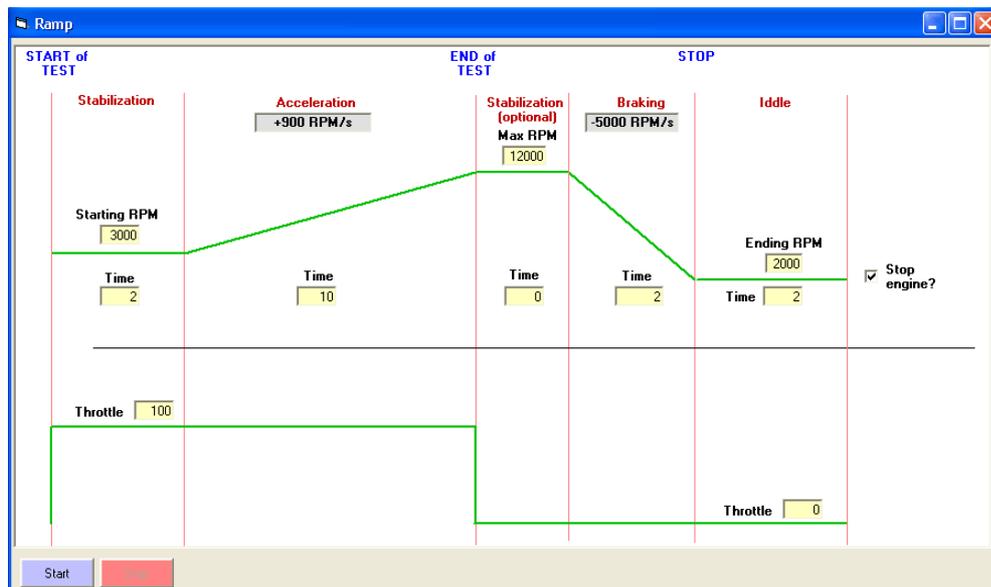
Future versions of the program will let the user to automate the dyno control.

As before, a stabilization period could be defined in order the system speed will be stable and for example for the turbocharger gets pressure.

Then, an acceleration period will be defined regardless the horsepower of the engine. The system will actuate over the brake so the system accelerates slowly up to the desired value.

Also, a braking period will be defined to slow down the system in a safe way up to the desired speed

The program can also be used to control the throttle automatically (in engine dynamometers)



Engine Test Cycles will be implemented later. This consists on a series of instructions to simulate real driving conditions like "press clutch", "engage first gear", "accelerate", etc.

This can be used to having an engine running several hours at test its reliability, and for pollution tests.

- **Retarder configuration:** (not implemented yet) Here is accessed the retarded table. Brake value vs. rpm in steps of 500 rpm or 250 rpm. The

user can find any rpm value by pressing several times this button, and then change with the right knob.

- **Device configuration:** Several configuration values can be changed here, by pressing several times on the button.