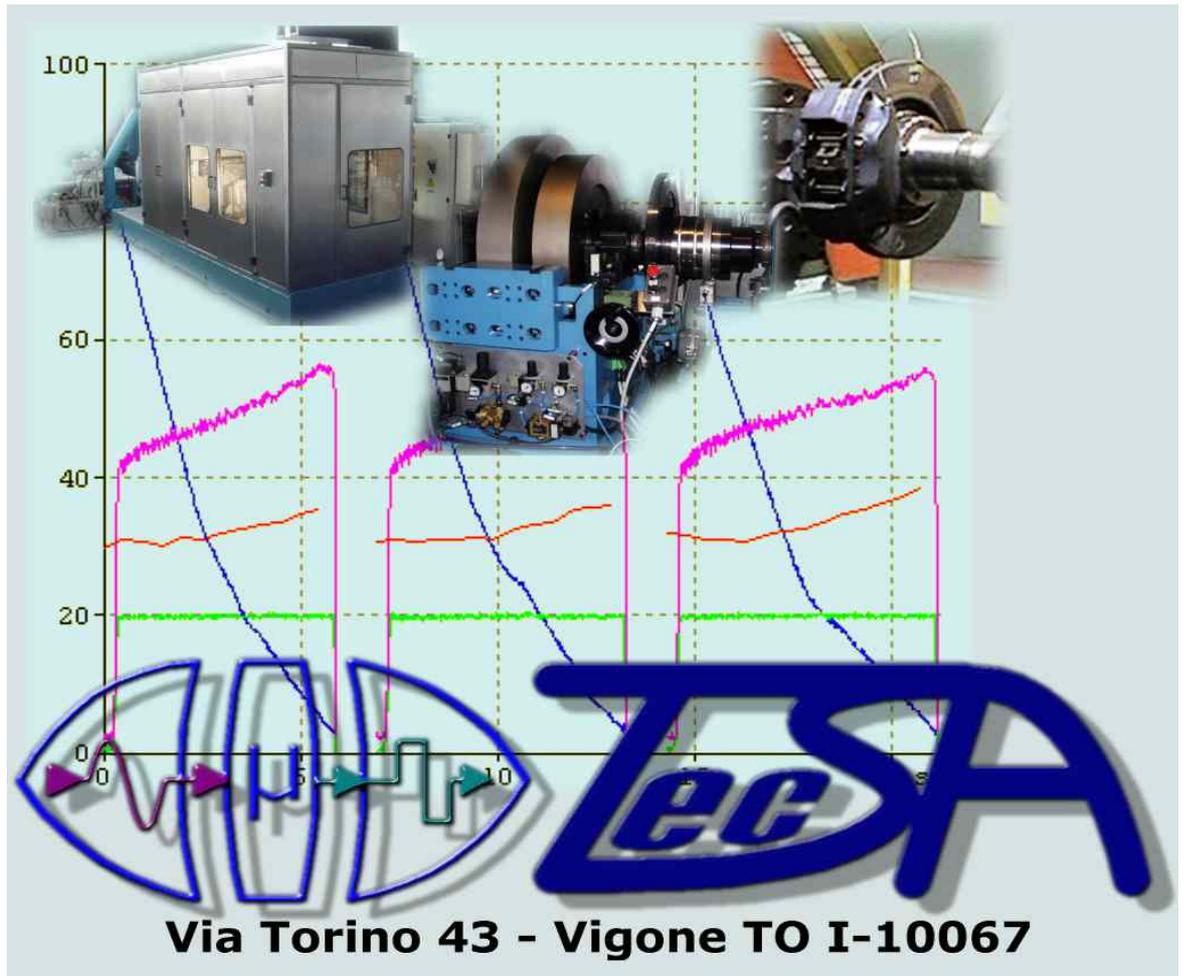


# Inertia Dynamometers



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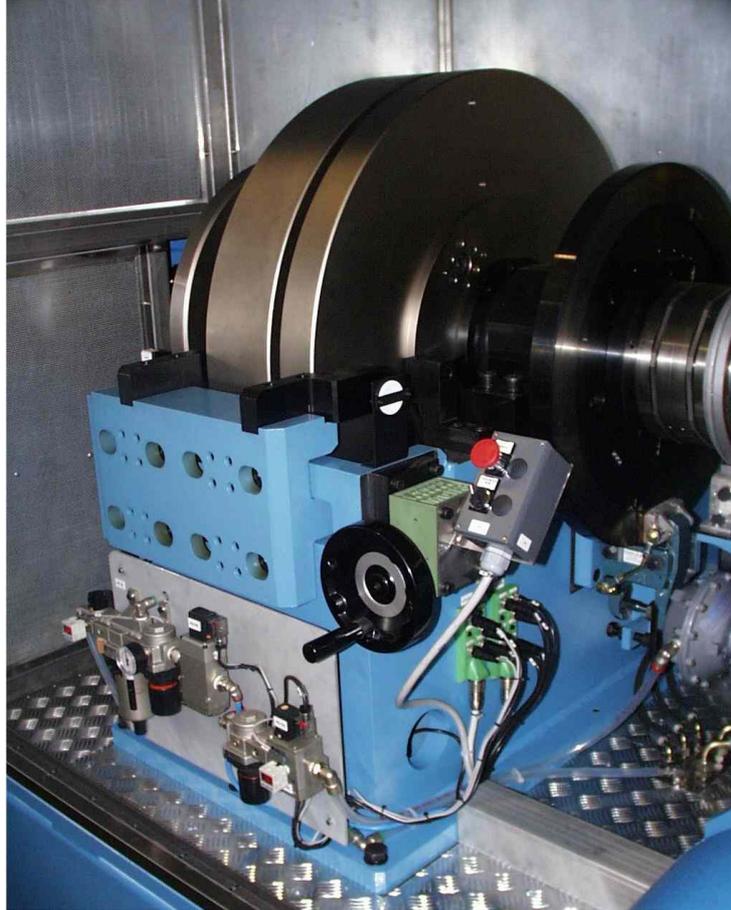
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## Architecture of the braking dynamometer with inertia simulation

Following is a brief description of an inertia dynamometer.

### General description

Illustration 1 Dynamometer inertia fly wheels



The inertial masses corresponding to  $\frac{1}{4}$  of the weight of the car are splined on the flywheel shaft.

The electric motor rotates the flywheel masses up to the number of revs required to simulate the speed of the vehicle. Subsequently, the brake is applied according to the method established in the test description.

Control may be of the following type: pressure, torque, force, position and mixed.

Braking is recorded and analysed in terms of braking moment, pressure trend, pump stroke, temperatures (of the disk, friction material, brake fluid), etc.

The dynamometer permits lab testing of the brake of a vehicle in real size.

The basic elements of the braking dynamometer are:

- ◆ the electric motor;
- ◆ the flywheel masses;
- ◆ the torquemeter for measurement of torque;
- ◆ the spindle (or section of shaft) for mechanical de-coupling of the torquemeter from the brake under test;
- ◆ the brake support slide;
- ◆ the hydraulic devices for actions on the pump and (optionally) on the cable of the hand brake;

- ◆ the hydraulic motor (optional) for static friction tests in which precise torque values modulated also at nil speed must be generated;
- ◆ the flywheel covers;
- ◆ the brake area enclosure which may be of three types: simple accident prevention cover, or semi-anechoic for noise tests, or anechoic and climate-controlled for sophisticated comfort tests.

The architecture described is that we propose as optimal for a modern braking dynamometer.

We consider use of a torquemeter extremely important as this permits various types of brake assembly with simpler equipment than that normally necessary in the case in which torque is recorded by means of the tailstock.

The main three types of brake assembly are as follows:

- ◆ classical: with the disk splined on the flywheel shaft and calliper supported by a saddle;
- ◆ with wheel hub: motion is transmitted to the disk by means of a coupling (for example a half axle) and the brake is fastened on the saddle using the arms of the wheel body;
- ◆ with suspension: in addition to the wheel hub, the suspension (or part of this) with or without load is also assembled on the test rig using a specific fixture.

## Inertia simulation

Inertia simulation is performed using an electric motor, adding or removing a certain amount of inertia to that of the flywheel masses.

The engine therefore remains active also during the braking phases.

The amount of inertia that can be simulated by the engine is directly proportional to the torque (and therefore the power) it can deliver and in inverse proportion to the vehicle deceleration to be obtained (and therefore to the braking moment to be applied).

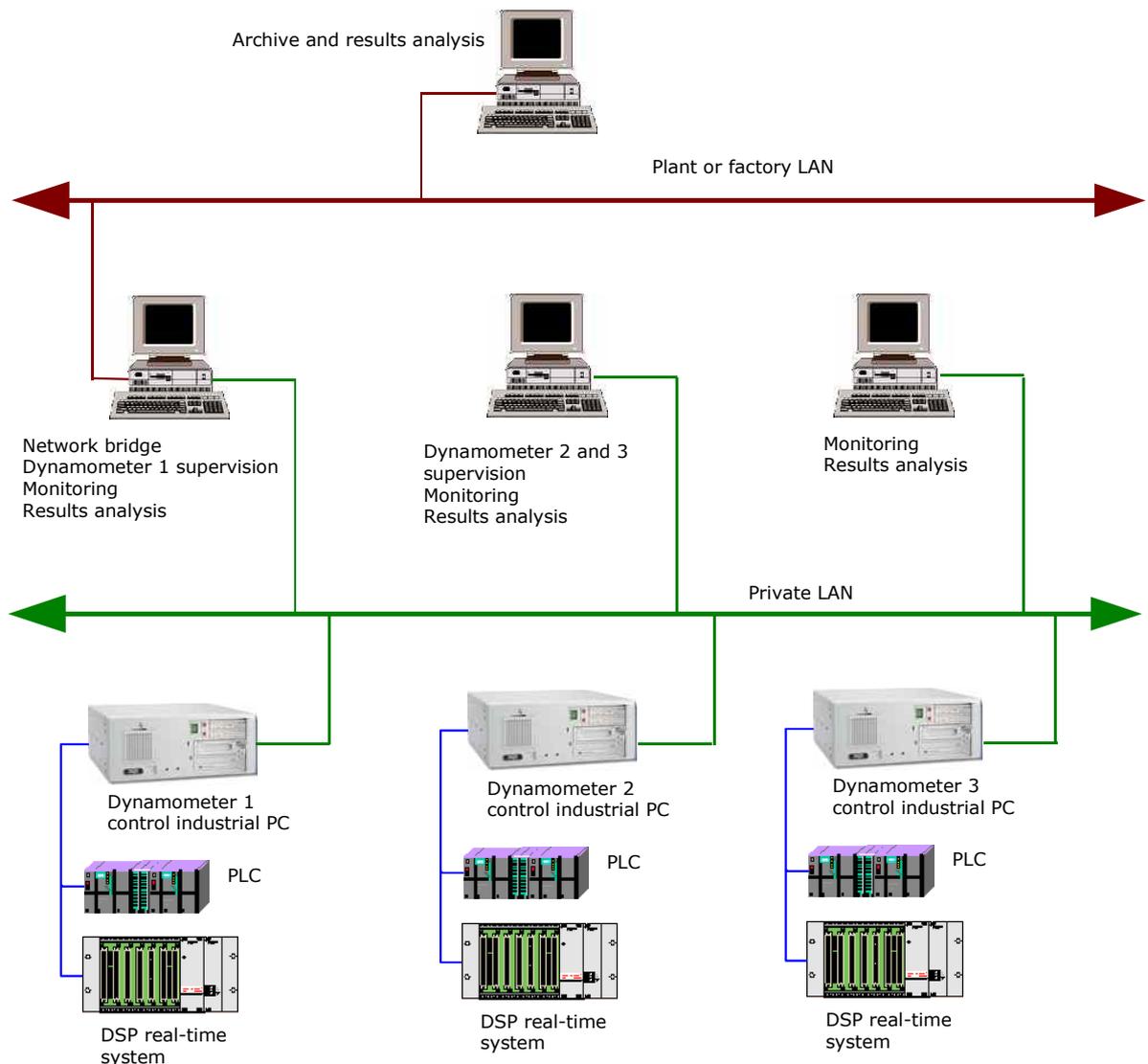
It is important that the test rig assures no interruption in inertia within its class of use. That is to say, it must be possible to cover the entire inertia of the category of vehicles for which it is intended taking into account top speed and maximum deceleration reached by these.

With an electric motor between 150 and 300 kW, it is possible to set up braking dynamometers with only 3 or 4 flywheel masses obtaining a good compromise between cost and performance.

An excessive number of flywheel masses tend to increase the costs of the mechanical part and, on the other hand, an over-rated electric motor involves a considerable cost for the electrical equipment.

# Architecture of the information technology applied to the test rig

Illustration 2 IT architecture



The informatics architecture is arranged on three levels:

- ◆ First level (optional): centralized management system of the data archives and analysis of the results.
- ◆ Second level: supervision system, monitoring and analysis of the results. The system consists of one or more PCs in network connection. Each PC supervises one or more dynamometers or executes the monitoring. There is no limit for the number of PCs that are only for monitoring tasks.
- ◆ Third level: control system. The control system consists of several industrial type PCs in network connection. Each PC manages the activities of one dynamometer. To each PC are connected a PLC (that manages the safety logics) and a system based on a DSP microcomputer (that manages the real time activity).

The operator controls one or more test rigs using a supervisor PC with Windows® NT operating system which, for reasons of safety, should be situated in an area from where the test rigs are visible.

Other monitoring PCs may be located in other offices. However, these PCs cannot send commands and they are able only to monitor running of the tests in real time.

Each test rig has a PC (with DSP) dedicated to control that does not have an operator interface as this function is provided by the supervisor PC.

A private network (LAN) assures communication between the various PCs: test rig 1, test rig 2, etc., supervisor 1, supervisor 2, etc., monitoring 1, monitoring 2, etc.

This network may be of the fiber optics type or with RJ45 (and related HUB).

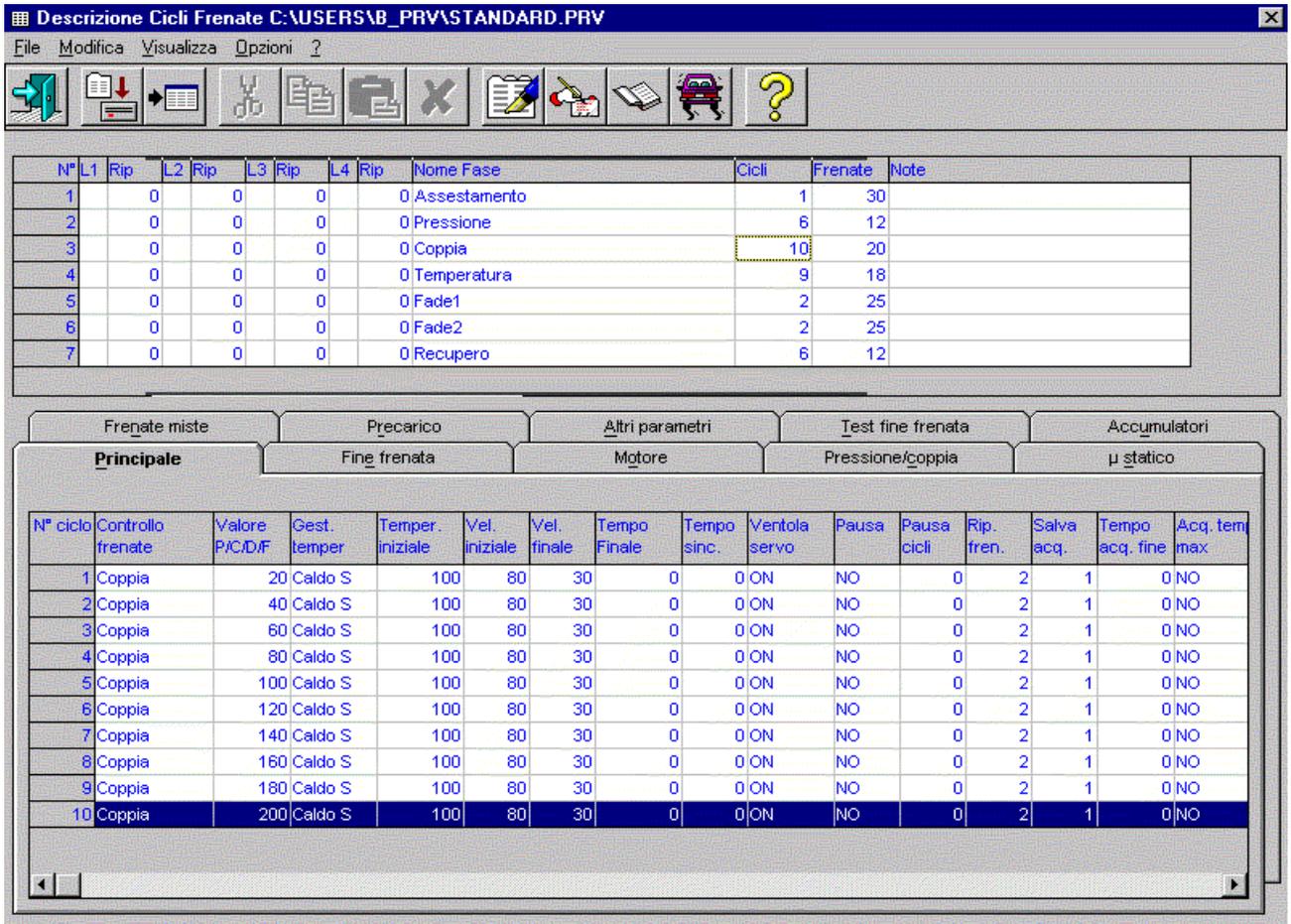
The control PC of the test rig runs under Windows® family operating system and DSP for real time. It therefore features a high performance multitasking and real time system:

- ◆ high speed acquisition: up to 10 kHz per channel, with a total throughput of 50 kHz, limited in time only by the memory of the micro and/or speed of the mass storage;
- ◆ digital filters on individual analog channels with the possibility of channel duplication for application of filters of varying degree according to use: monitoring, Time History, control loop;
- ◆ channels processed on line that are obtained linking different physical dimensions such as for example in the case of "friction coefficient channel ";
- ◆ closing of a high frequency loop: up to 1 kHz per loop with total throughput of 10 kHz;
- ◆ precise identification of the moments of signal transition, of exceeding of thresholds, safety values, alarms, with corrective actions or blocking within one hundredth of a second;
- ◆ digital PID functions using the Z transform, with the possibility of instantaneous exchange of the control values, such as for example Force/Position.

# Dynamometer management system

## Description of the tests

Illustration 3 test description screen snapshot



The screenshot shows a Windows application window titled "Descrizione Cicli Frenate C:\USERS\B\_PRIV\STANDARD.PRIV". The window contains a menu bar (File, Modifica, Visualizza, Opzioni), a toolbar with various icons, and two main data tables.

**Table 1: Test Phases**

N°	L1	Rip	L2	Rip	L3	Rip	L4	Rip	Nome Fase	Cicli	Frenate	Note
1		0		0		0		0	0 Assestamento	1	30	
2		0		0		0		0	0 Pressione	6	12	
3		0		0		0		0	0 Coppia	10	20	
4		0		0		0		0	0 Temperatura	9	18	
5		0		0		0		0	0 Fade1	2	25	
6		0		0		0		0	0 Fade2	2	25	
7		0		0		0		0	0 Recupero	6	12	

**Table 2: Detailed Parameters**

N° ciclo	Controllo frenate	Valore P/C/D/F	Gest. temper	Temper. iniziale	Vel. iniziale	Vel. finale	Tempo Finale	Tempo sinc.	Ventola servo	Pausa	Pausa cicli	Rip. fren.	Salva acq.	Tempo acq. fine	Acq. tem max
1	Coppia	20	Caldo S	100	80	30	0	0	ON	NO	0	2	1	0	NO
2	Coppia	40	Caldo S	100	80	30	0	0	ON	NO	0	2	1	0	NO
3	Coppia	60	Caldo S	100	80	30	0	0	ON	NO	0	2	1	0	NO
4	Coppia	80	Caldo S	100	80	30	0	0	ON	NO	0	2	1	0	NO
5	Coppia	100	Caldo S	100	80	30	0	0	ON	NO	0	2	1	0	NO
6	Coppia	120	Caldo S	100	80	30	0	0	ON	NO	0	2	1	0	NO
7	Coppia	140	Caldo S	100	80	30	0	0	ON	NO	0	2	1	0	NO
8	Coppia	160	Caldo S	100	80	30	0	0	ON	NO	0	2	1	0	NO
9	Coppia	180	Caldo S	100	80	30	0	0	ON	NO	0	2	1	0	NO
10	Coppia	200	Caldo S	100	80	30	0	0	ON	NO	0	2	1	0	NO

The test braking operations are described individually with the possibility of specifying around 100 parameters for each. The "copy and paste" technique, together with the possibility of specifying repetitions of individual braking operations or of groups of these at several levels, promote particularly simple fast programming.

## Running of the tests

Once started, a test is completed by the dynamometer in complete safety, also without surveillance by an operator.

The front-end system of the dynamometer provides the operator with several monitoring environments during the test. These return information on the status of the test both at general level (number of braking operations performed, result of the last braking performed, phase of the current braking operation, etc.), at detail level (graphic display of the trend of one or more analog values during the last braking operations performed, monitoring of the logic and analog I/O channels, etc.).

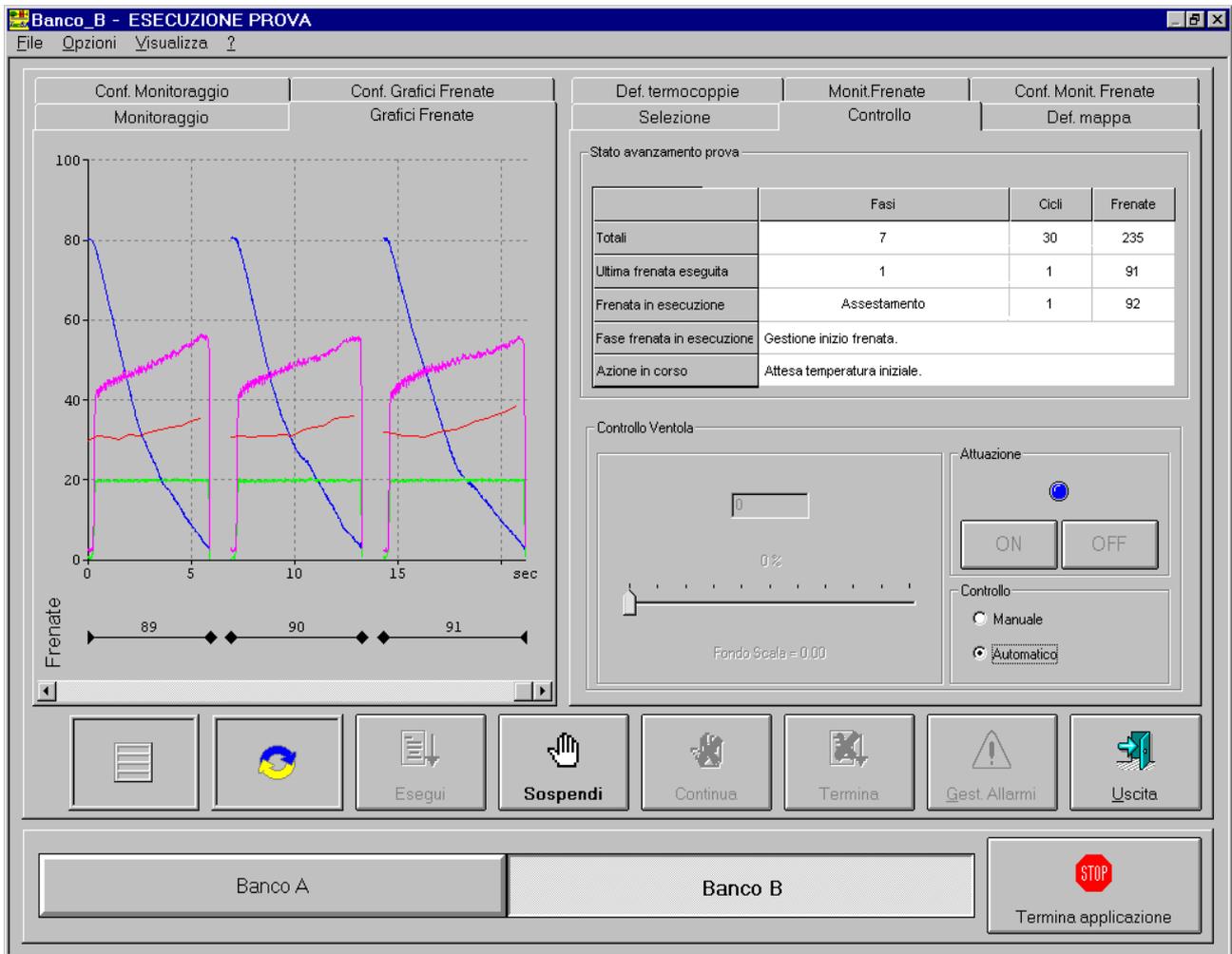
The function of graphic display of the trend of analog values completely replaces the conventional paper logger. It is possible to store a number of braking operations limited only by mass storage capacity. The system permits analysis of braking stored with the possibility of full-screen display, of variation in scale and activation or de-activation of the individual curves.

As already mentioned, the dynamometer is able to manage the running of a test also in unattended mode. This means that the operator can use the front-end computer of the system for other purposes, such as filing and/or processing of results or, more generally, office work. In this case, a specific function (Bench Alerter) performed at "service" level by the Windows® NT/2000/XP operating system, continuous to inform the operator of changes in test rig status.

These are, for example, alarms, programmed pauses, and completion of the current test.

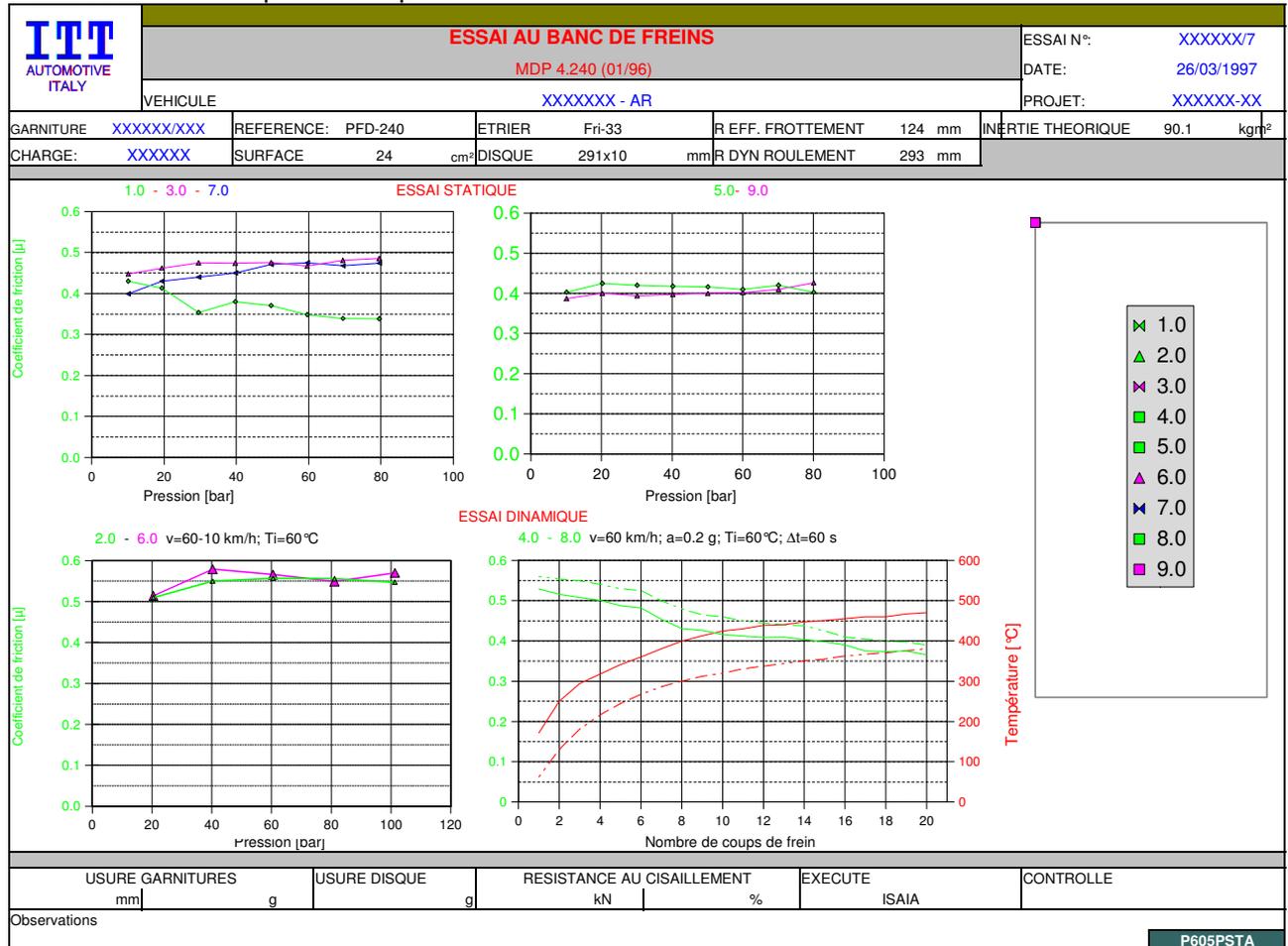
Obviously, the network connection of the control system permits remote monitoring of test rig activities and transfer of results to centralized databases.

Illustration 4 Control system screen snapshot



## Results of the tests

Illustration 5 Example of a report



The results of the tests are divided into [numeric results](#) and [Time History data](#).

### Numeric results

The numeric results, organized in tables in which each line provides the results of a braking operation, are typically average, maximum, minimum values of the dimensions acquired, the friction coefficient, etc.

The operator can choose the results required from the vast set available and can specify the type of sorting of the columns. This may also be modified dynamically in the case in which the results of a test are displayed using the front-end system of the test rig.

Calculation formulas applied to the set of predefined results can also be included in the results of a test.

### History Time data

Regardless of the type of monitoring performed by the operator to check the trend of the test, Time History storage of the values acquired for the various channels can be selected during description of this.

For each channel, it is possible to specify the acquisition frequency, application of any filters and the observation period (all or part of the braking operation).

Also in the case of Time History data, calculation formulas applicable to the dimensions acquired can also be specified. In this way, processed channels are obtained; a typical example of which is the channel of the instantaneous friction coefficient.

The Time History file is generated in a standard format recognized by all electronic spreadsheets or database managers running under Windows®.

NOTES:

## European auto-maker tests supported

During ten years' business in the road and laboratory brake tests sector, we have accumulated the experience required to set up the hardware and software system which, as it is "turn key", can carry out the typical tests of the main European automotive manufacturers.

This has been achieved following up suppliers of friction material and braking assemblies step by step in their relationships with European Customers.

The following tests are supported:

- ◆ Fiat;
- ◆ Renault (from whom we received the hardware and software certification with a score of 97/100 assigned to test rig num. 7 of ITT of Barge and 99/100 for the Brembo rigs);
- ◆ PSA;
- ◆ Ford;
- ◆ Volkswagen;
- ◆ Mercedes;
- ◆ BMW;
- ◆ Volvo.

The following test methods are obviously supported:

- ◆ AK-1                               for braking dynamometers;
- ◆ AK-2                               for braking dynamometers;
- ◆ AK-Master                       for braking dynamometers;
- ◆ ECE R90, R13                   for braking dynamometers
- ◆ Eurospec                         for small friction test type machine;
- ◆ AK – noise matrix             for comfort test rigs.

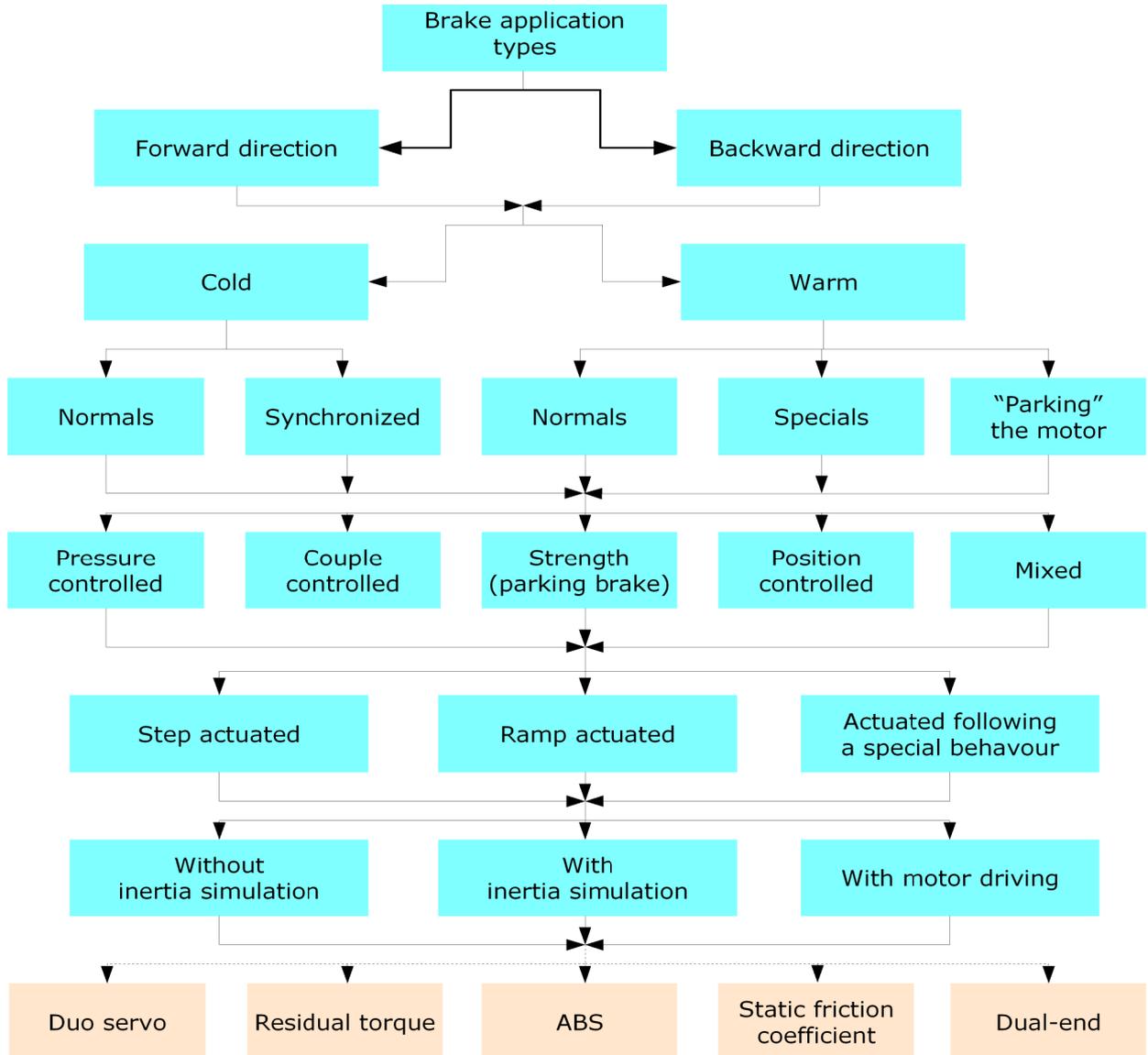
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## Type of brake applications

Brake applications may differ according to various parameters that can be combined in a vast number of different ways.

An explanatory diagram is provided below. From the top down, combining the various boxes, an overview of possible types of braking is obtained.

Illustration 6 Type of brake applications available



bkrappltypes\_en.sxd

## Direction of travel during brake application

Brake applications may be carried out both during forwards travel and reverse (by convention, the direction of forwards travel is indicated as clockwise rotation looking at the test rig from the front).

Normally, a test includes all the brake applications in the same direction of travel. To manage brake applications with both directions of travel in the same test, a test rig with the following characteristics is required:

- ◆ motor with bi-directional motion that is activated by inverting only the reference polarity;
- ◆ presence either of a torquemeter for recording of torque or a traction and compression load cell.

## Start of brake application control method: cold and hot

The start of brake application may be COLD or HOT. In cold brake application start, no check is made on the start of brake application temperature whereas hot brake applications are started when the temperature reaches a certain preset value.

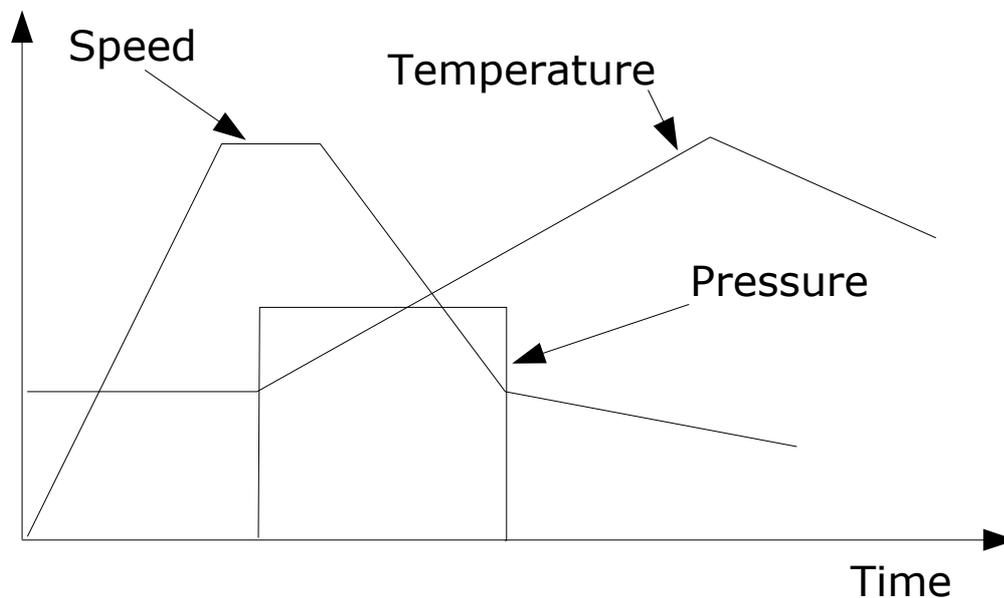
There are five different types of start a brake application:

- ◆ normal cold
- ◆ synchronized cold
- ◆ normal hot
- ◆ special hot
- ◆ hot with parking speed

### Normal cold brake applications

Normal COLD brake application is performed in cascade without taking into account their initial temperature: once the engine has reached the target speed required, braking is applied immediately (see Illustration 7).

Illustration 7 Diagram of normal cold braking operations

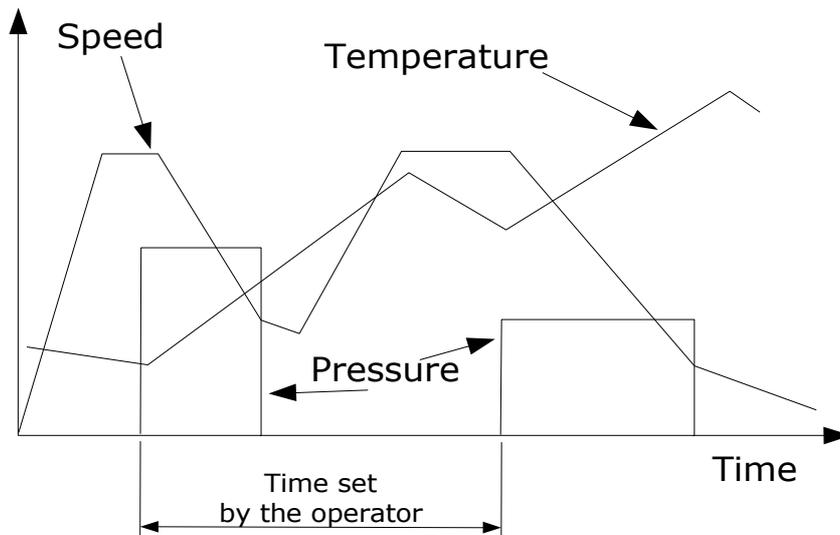


### Synchronized cold brake applications

In synchronized COLD brake applications, the instant of application of the pressure/torque reference is regulated by a stopwatch, the duration of which is set by the operator during the cycle description phase.

Once the engine has reached the target value, there is a wait with the engine running until the time required by the operator has passed before applying the brake (see Illustration 8).

Illustration 8 Synchronized cold brake application diagram



### Normal hot brake applications

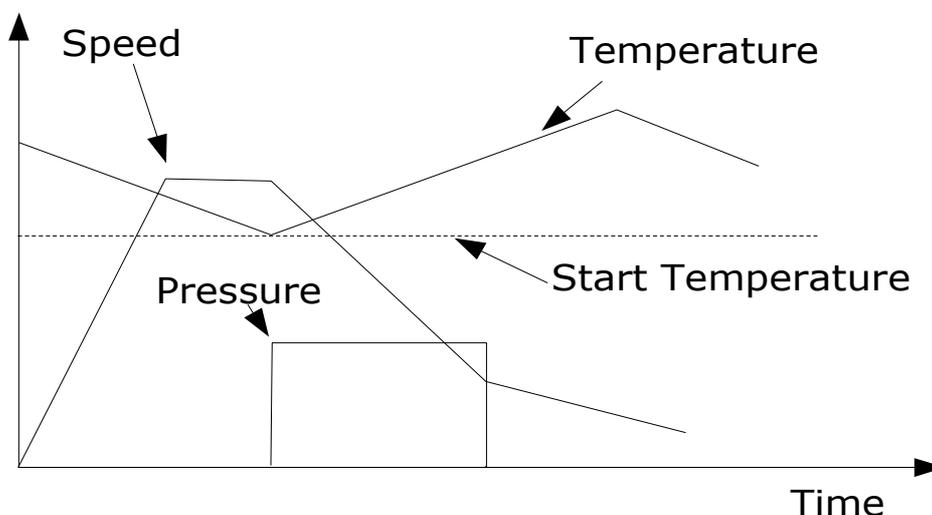
In normal HOT brake applications, there is a wait for the temperature to drop to the start value with the engine at the target speed. When this is reached, brake is applied immediately.

In the case in which the temperature is below the one set for start of brake application, pre-heating brake application must be performed. The pre-heating brake applications are constant pressure brake applications used only to increase temperature. They are normally characterized by low pressure and low speed.

The procedure for hot brake application is as follows:

- ◆ running of any pre-heating operations in order to increase temperature;
- ◆ activation of the engine to reach the brake application speed;
- ◆ wait for the temperature to drop to the start value;
- ◆ brake is applied.

Illustration 9 Normal hot brake application diagram



### Special hot brake applications

Special HOT brake applications consist of two separate phases:

- ◆ wait for run up to temperature with the engine running (as for normal hot brake applications);
- ◆ wait for temperature after switching off the engine.

The first phase is identical to normal hot brake application, with a wait for the temperature to drop with the engine running.

If the temperature drops within a time established by the operator, brake is applied immediately. If it does not drop within the time established, the engine is switched off and left to run only through inertia, gradually slowing its movement.

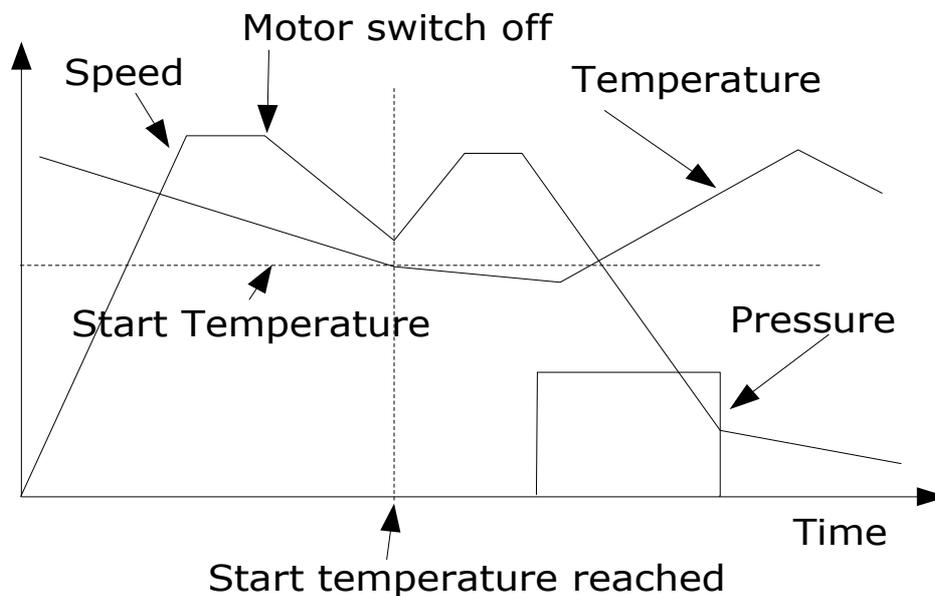
Once the start temperature plus a certain delta (difference) has been reached, the engine is re-started, wait until it reaches the target speed and then brake is applied.

This type of brake application is useful when the pads, which have swollen due to the increase in temperature, rub against the disk preventing the disk cooling.

The special hot braking procedure is as follows:

- ◆ any pre-heating in order to increase temperature;
- ◆ activation of the engine to reach the required speed ;
- ◆ wait for the temperature to drop to the start value;
- ◆ switch off the engine after a pre-established time;
- ◆ wait for the temperature to drop to the start value plus a delta;
- ◆ re-start of the engine and wait for run up to initial brake application speed;
- ◆ brake is applied.

Illustration 10 Special hot brake application diagram



### HOT brake applications with parking speed

HOT brake applications with parking speed are similar, in the same cases, to [Special Brake Applications](#) .

During these operations, the engine is not brought to the target speed required but to a lower speed (known as the parking speed). When the start braking temperature plus a delta is reached, the engine is brought to target speed and braking is performed.

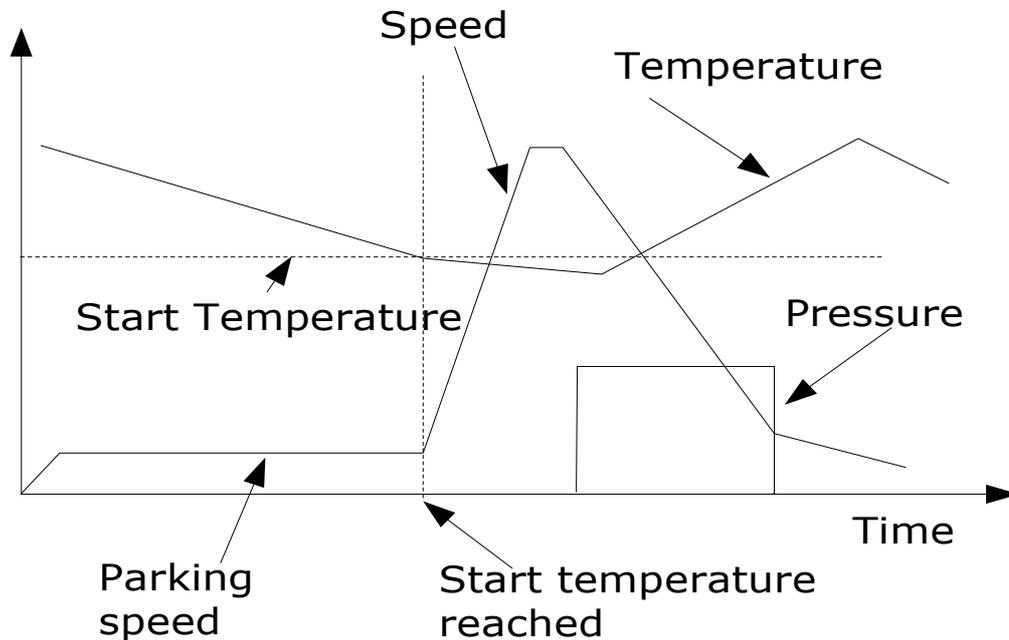
Parking speed may also be set to 0. In this case, the engine is not even started and the wait for the temperature to drop takes place with the engine stopped.

The hot brake application with parking speed procedure is as follows:

- ◆ any pre-heating cycle to increase temperature;

- ◆ activation of the engine to reach the parking speed set;
- ◆ wait for the temperature to drop to the start value plus a difference;
- ◆ re-start of the engine and wait for this to run up to start of the brake application speed;
- ◆ brake is applied.

Illustration 11 Hot brake application with parking speed diagram



## Brake applications control values

Brake applications can be controlled with constant pressure, constant torque, constant deceleration or constant force in the case of the hand brake.

During constant pressure brake applications, the pressure remains unchanged from the start to the end with a concurrent variation in brake application torque.

In constant torque brake application, the couple remains constant from the start to the end of the brake application with a concurrent variation in pressure.

Constant deceleration brake applications are in fact constant torque brake applications but the program according to the deceleration set and the inertia to be simulated or effectively present on the test rig calculates the torque value automatically.

In force type brake applications, traction on the bowden cable (controlled by a load cell) is maintained constant.

### Brake applications with transitory or with servovalve ramp

Pressure or torque or force may be increased in steps or according to a ramp.

In step brake applications, the pressure rises to the target value required as quickly as possible whereas in ramp type brake applications, a straight line is calculated and the pressure or torque value are increased progressively.

For example, the operator may ask to increase pressure in 1 second.

The pressure increase speed in step-type brake applications is around 0.05 - 0.2 seconds.

### Brake applications with transitory or with speed ramp

Similarly to pressure, speed can be controlled in steps or ramp fashion.

In step brake applications, the final target value is set and the increase in speed depends on

the power of the engine and the inertia physically present on the test rig.

In ramp type brake applications, speed is increased according to a linear ramp, establishing successive incremental targets.

Step type or ramp increase is selected individually for each cycle.

### Brake applications with different types of servovalve references

There are various types of servovalve reference control during brake applications:

- ◆ constant (constant reference throughout the brake application);
- ◆ mixed (the brake application is divided into three or more parts with different reference values);
- ◆ combined (the reaction value may be changed during the brake application);
- ◆ theoretical (reference given by a speed and time function =  $f[v, t]$ ).

In constant reference brake applications, the target value set remains constant throughout brake application.

In mixed reference brake applications, the application is divided into three or more intervals, each of which has a different target value. The duration of the various sections may be scaled according to speed and according to time.

Combined brake applications can be those in which torque braking with a high value is required but a maximum pressure limit is not to be exceeded. If, during brake application, in order to maintain the torque target, there is a tendency to exceed the maximum pressure value set, the feedback software switch takes place and the brake application is completed with constant pressure equal to the threshold value set.

In brake applications with theoretical simulation of the reference, the reference is varied on the basis of speed and time according to a 2nd level polynomial (normally a parabola) in which the operator sets the coefficients.

### Brake applications with different types of engine references

There are three types of engine reference control during brake applications:

- ◆ without inertia simulation;
- ◆ with the engine driving at constant speed;
- ◆ with inertia simulation.

### Brake applications without inertia simulation

Brake applications without inertia simulation are classical brake applications, that is those in which the engine is switched off in the case of action of the servovalve: deceleration depends only on the physical inertia of the test rig (flywheels + friction).

### Brake applications with engine driving

Brake applications with the engine drive is used to simulate long alpine down-hill sections (or for the small friction machine type test) in which the driver keeps his foot slightly pressed on the brake pedal without this reducing the speed of the vehicle.

Relatively low pressure/torque values and constant speed distinguish these brake applications throughout the application.

The end of the application is usually set both according to time and temperature so as to avoid overheating of the material.

To carry out these brake applications, a suitably powered engine is required, it must be able to deliver a torque such as to offset that present on the brake.

## Brake applications with inertia simulation

Brake applications with inertia simulation are intended to be used when, with the flywheels present on the test rig, it is not possible to set a precise value of the vehicle inertia.

Actually, they are of general use in that they make it possible to recover, with the engine, those slight differences in inertia that exist on any test rig due to other mechanical components (bearings, shaft, etc.).

The inertia simulation theory consists of using the force of the engine to simulate a mechanical resistance to the brake application force. This force of the engine can be used both to increase the inertia of the test rig and to reduce it.

The amount of inertia that can be simulated is a direct proportion of the power of the engine (maximum motor torque) and inversally proportionate to the deceleration to be obtained.

During braking, the engine remains active to provide or remove the inertia required for simulation.

The simulation algorithm envisages a decrease in the theoretical speed according to the average torque found between the previous and the current sampling.

The control loop performs the following operations:

- ◆ recording of current torque;
- ◆ calculation of the theoretical speed decrease;
- ◆ calculation of the new target speed.

## Brake applications with acquisition after end of the application

Time history acquisition normally terminates at the end of brake application. In some cases, it is useful to continue acquiring the signal values also for a certain time after the brake application has ended. This is useful for example, to calculate residual torque or to analyse the temperature trend of the material and brake fluid after a number of consecutive high temperature brake applications (e.g.: in the last brake application of a simulation of an alpine down-hill section).

In this case, the operator selects the number of seconds during which the system must continue acquisition after the end of the brake application (this may even be a very high value, > 1 hour).

## Brake application with or without initial pre-load

Pressure or torque value may be increased in step or ramp fashion. In the first case, the target value is given immediately and the time taken to reach this value depends on the characteristics of the hydraulic system; in the second case, pressure or torque is increased providing references that increase in linear mode in time.

In some cases, it is necessary to apply a low pressure (or torque) value for a limited time before performing the step or ramp. This value, known as pre-load, may be useful in the following cases:

- ◆ in brake applications in which the 'no-load' stroke time of the servovalve in the ramp or step type increase is not to be considered;
- ◆ in brake applications in which a resistance inside the calliper caused by springs or other systems is to be overcome before applying the pressure target value.

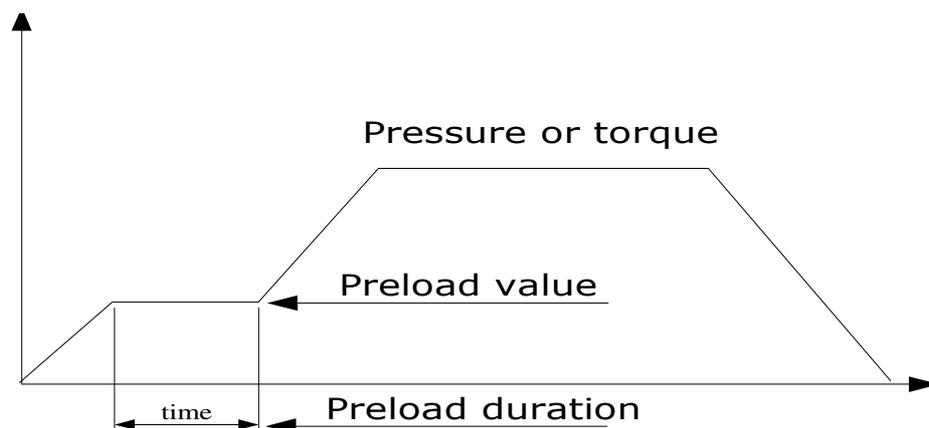
The pre-load value may be set in two ways:

- ◆ as pressure or torque engineering value;
- ◆ as percentage of the target value.

In the first case, the pre-load value is fixed (e.g.: 10 bar, 8 daNm, etc.) while in the second case, the value depends on the target value. For example, if a pre-load of 10% of the target value is required and the target value is 50 bar, the pre-load value is 5 bar.

The user sets pre-load duration in seconds.

Illustration 12 Brake application with or without initial pre-load



The operator can choose whether or not to consider the pre-load time into the total ramp execution time.

In the first case, the run-up time to pre-load and the actual pre-load time are subtracted from the total ramp time while in the second case the ramp time required remains unchanged using the pre-load pressure value as reference.

## Brake applications with use of average torque and pressure value accumulators

At the end of braking, it is possible to store the average pressure or average torque value in specific accumulators in the program. The value to be stored is added to any value already present in the accumulators: the average value thus obtained can be used as target value in subsequent braking operations.

The pressure value is stored in the case of torque braking and the torque value in the case of pressure braking. In this way, it is possible to record the average torque resulting from a set of braking operations carried out at the same pressure and to use this to carry out constant torque braking. There is no limit on the number of values that may be stored in the accumulator and there is also no limit on the number of accumulators that can be used in the same test.

The operator identifies the accumulator with a name consisting of maximum 16 characters.

To use a value held in an accumulator, it is sufficient to indicate the name of an existing accumulator.

If the operator specifies a name not yet used, the program creates the accumulator initializing its contents with the value to be stored; if the accumulator indicated already exists; it adds the value to be stored to the contents of the accumulator.

From this moment on, the accumulator created remains active until the end of the test even if this is interrupted and then restarted. The values are saved in a temporary file, which is deleted when the entire test has been effectively completed.

The same accumulator can be reset and re-used several times during a test.

The accumulator-reset option is useful in the case of repetition of cycles in that, in this case, the operator can decide whether the contents of the accumulator are to be reset at each repetition or whether to continue adding its values.

For example:

cycle num. 1 (at constant pressure)	saves the torque value in acc. ACC1
cycle num. 6 (at constant pressure)	saves the torque value in acc. ACC1
cycle num. 11 (at constant pressure)	saves the torque value in acc. ACC1
cycle num. 16 (at constant pressure)	saves the torque value in acc. ACC1
cycle num. 17 (at constant torque)	uses the average value contained in ACC1

At cycle 17, cycle repetition starting from cycle number 1 has been set for 10 times.

If, at cycle 1, the operator has set accumulator reset mode, at cycle 17 the accumulator will still contain the sum of four values (the average torque values of cycles 1, 6, 11, 16).

If, at cycle 1, the operator has not set accumulator reset mode, at each cycle repetition this will increase its total by the sum of four values each time. The first time, in cycle 17, the average of the four values will be used, the second time the average of eight values will be used, and so on.

## Delivery fan management mode

The braking block cooling fan (also known as delivery fan) can be driven in various ways.

describing the test, the operator indicates how the fan is used, as follows:

- ◆ the fan is not to be used during braking;
- ◆ the fan is to be used in all phases of braking;
- ◆ the fan is to be used only in certain phases of braking;

With the first option, the operator indicates that the fan is not to be used in any of the braking phases.

With the second, the operator indicates that the fan is to be used in all braking phases.

With the third, the operator indicates the fan is to be used only in certain braking phases, that is to say:

- ◆ off during pre-heating;
- ◆ on while waiting for the temperature to drop to start value;
- ◆ off during actual braking;
- ◆ on after the end of braking and while waiting for maximum temperature.

In each cycle, the operator also selects fan rotation mode that may be:

- ◆ fixed rpm valid in all braking phases;
- ◆ a number of revs proportional to engine revs.

In the first case, the speed of the fan does not change as engine speed decreases remaining therefore at a constant number of revs; in the second case, fan speed varies according to changes in engine speed, maintaining however a fixed proportion with this.

This second possibility is used to simulate the variation in the amount of air that heats the brake during braking in that as the speed of the vehicle gradually decreases, the amount of air and the power of this are also reduced.

## Dynamic calibration of values: PI and AUTOCALIBRATION constants

For correct dynamic management of reference values during braking and between one braking and the next, there are two possibilities:

- ◆ use of integrative and proportional actions;
- ◆ dynamic auto-calibration of the values.

The integrative and proportional actions intervene dynamically during braking immediately modifying the reference value according to differences encountered in the values acquired.

There is a pair of PI constants for each reference managed (pressure, torque, speed, and fan) and these can be activated or de-activated in different ways.

### Proportional action

This is the carry-over on subsequent activation of the difference encountered between the target value required and the value found during current sampling. It is used for immediate correction of the difference between the target and actual data.

Error recovery depends on the value of the KEP constant.

### Integrative action

The sum of the errors encountered between the target value and the current value is used to reset the average error in time. The value applied is the sum of the error multiplied by the KEI constant.

The difference between the proportional action and integrative action is that the first is intended for immediate correction of the target value while the second tries to recover the average value obtained in time. The integrative action involves the disadvantage of extending the error in the opposite sign to that encountered so far.

The integrative action is managed as follows:

- ◆ error accumulator EI cleared to zero at the start of braking;
- ◆ the EP error between the target value required and the current value is calculated for each sampling;
- ◆ the error calculated is added to the previous errors;
- ◆ at the next command, the target value required is applied plus the sum of the errors multiplied by constant KEI.

Dimensioning of this constant is carried out on an experimental basis and may vary from test rig to test rig.

### P.I. adjustment in engine action

Proportional correction is useful in all phases of engine control:

- ◆ during step-type acceleration;
- ◆ during ramp-type acceleration;
- ◆ during inertia simulation, both theoretical and taken from time history.

The integrative action is useful only during the upward ramp and during the inertia simulation phase.

During speed setting, the PI constants must be set to 0 in that these never modify the reference value applied.

Dimensioning of the constants may vary considerably from test rig to test rig and also according to the type of test to be carried out on the same test rig in that the factors that affect this are both the power of the engine and the mechanical inertia effectively present on the test rigs.

With low inertia values and with prompt engine response, the value of the constants must be low (to avoid triggering possible oscillations), whereas with high inertia values and slow engine response, the value of the constants must necessarily be higher in order to make the corrections effective.

### P.I. adjustment in servovalve action

Three factors must be taken into account for adjustment of servovalve action:

- ◆ there is an initial delay in response caused by an initial no-load stroke of the actuator cylinder;

- ◆ subsequently, system response is very prompt in that strong changes in pressure occur at minimum variations in stroke;
- ◆ natural oscillations caused by wobbling of the disk may occur in torque tests.

Taking into account these factors, it is evident that it is advisable to use the software constants only during the effective pressure/torque application phase.

The value of the constants must be established experimentally for each test rig, even though, compared with the engine, there is no external dimensioning that may recommend a considerable change in their value.

### Dynamic auto-calibration of values

Dynamic auto-calibration of values means the carry-over of the error between the value applied and the value obtained on the target value of the next braking operation.

It intervenes only on the reference of the servovalve (pressure/torque).

The basic difference between integrative/proportional actions and dynamic auto-calibration of values is that the first intervene on the current braking operation, while the second intervenes on subsequent braking operations.

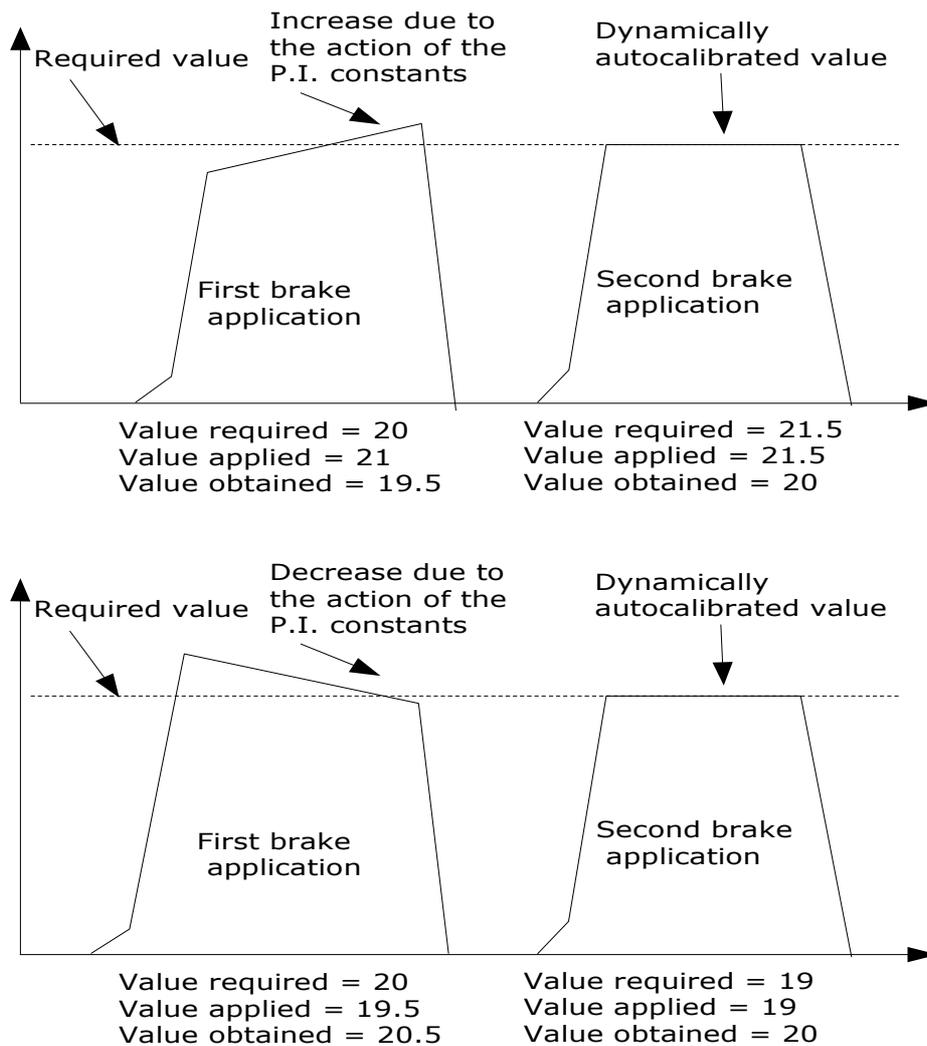
Auto-calibration is always useful but in particular in the following cases:

- ◆ in the case of not optimally set application software constants;
- ◆ in the case of a deviation of the hydraulic system due to the increase in oil temperature.

This correction does not eliminate the different response of the hardware (e. g.: I ask for 20 bar and obtain 22 bar) but makes it possible to overcome this and to obtain precisely the value required.

Integration of auto-calibration and the proportional and integrative actions makes it possible to obtain perfect braking throughout the test, also reducing the incidence of the P.I. constants and the presence of any initial peaks or steps.

Illustration 13 Dynamic auto-calibration of values



The theory of operation is as follows:

- ◆ at the end of each brake application, the application error is calculated, subtracting the average value obtained from the average value applied;
- ◆ this value is saved in a matrix containing both the errors and the value required of the last five braking applications performed;
- ◆ an offset that is added to the pressure value to be applied is obtained from this table;

The calibration is reset each time that:

- ◆ servovalve control method is changed (from pressure to torque and vice versa) ;
- ◆ there is a pause in the cycle, whether this has been programmed or forced.

## Pre-heating

Pre-heatings are constant pressure brake applications used, before hot brake application, to increase the temperature of the material when this is below the start of brake application value.

The pre-heating braking parameters are set during the test-programming phase and are common to all cycles of the test.

The number of pre-heatings varies from cycle to cycle because there are cycles before which a high number of pre-heating operations are carried out and there are other cycles before which no pre-heating is carried out in order to avoid repercussions on the results obtained in subsequent braking operations so that these can no longer be compared with other tests carried out previously.

Pre-heating braking may terminate when:

- ◆ the stop braking speed is reached;
- ◆ the stop braking temperature is reached.

The stop braking temperature is calculated adding an offset to the next start of braking temperature. The highest value between an engineering difference specified by the user and a percentage of the start braking temperature value is used as offset.

### Example num.1

The data are:

engineering offset specified by the operator	= 10°C;
percentage difference start of braking value	= 10%;
start of braking temperature	= 60°C.

In this case, the engineering offset introduced by the operator is used in that the 10 degrees set are higher than the 6 calculated as 10% of 60 degrees.

The pre-heating stop braking temperature is therefore:  $60 + 10 = 70$  degrees

### Example num. 2

The data are:

engineering offset specified by the operator	= 10 °C
percentage difference start of braking value	= 10%
start of braking temperature	= 300°C,

In this case, the percentage offset is used in that the 10 degrees set by the operator as engineering offset are lower than the 30 calculated as 10% of 300 degrees.

The pre-heating stop braking temperature is therefore:  $300 + 30 = 330$  degrees

## Configuration of the pilot thermal-couple

The pilot thermal-couple is the thermal-couple used to drive braking.

This may be any of the thermal-couples present on the test rig. The pilot thermal-couple is selected when starting the test.

Some tests require the possibility of controlling the test using not just one but several thermal-couples. This is usually the case when the test requires thermal-couples that record the temperature of both pads. In this case, the operator can choose from the following options.

- ◆ Use of the thermal-couple with the highest value of those indicated. This means that, for start braking, there is a wait until the temperature of both thermal-couples drops to the start value. The last thermal-couple to reach the start value (which therefore has a higher temperature than the other), will be that used from now on to drive braking
- ◆ Use of the thermal-couple with the lowest value of those indicated. This means that, for start braking, it is sufficient that one of the two thermal-couples drops to the start value. This thermal-couple is that used to drive braking
- ◆ Use of the average of the values of the thermal-couples indicated. Throughout braking, the temperature used will be the arithmetic average of the values of the two thermal-couples indicated.

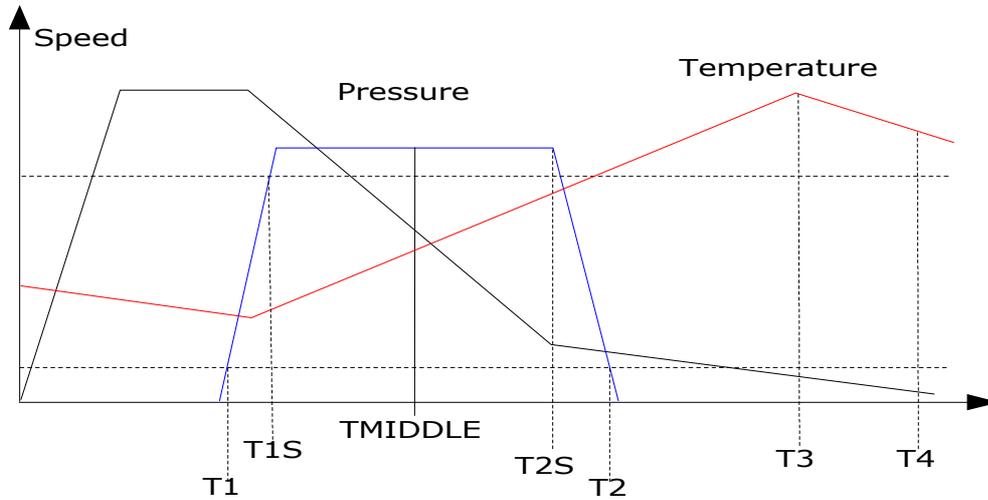
## End of brake application result calculation formulas

Immediately on completion of current brake application, the control process processes the time history (the logged data) acquired for calculating the test results. The number and types of values to be calculated may differ from test rig to test rig even though a certain number of values are standard and common to all of these.

The time history is scanned in time fashion from the start to the end. Each result to be calculated is characterized by a precise processing interval within the brake application.

In each braking operation, it is possible to highlight 4 main instants and a variable number of secondary instants, see the following Illustration 14.

Illustration 14 End of braking results calculation formulas



The main instants are calculated on the pressure or torque channel as specified below.

- ➔ Instant T1: the time at which the pressure or torque starts to increase and exceeds the noise threshold set (typical value 2 bar or 2 daNm);
- ➔ Instant T2: the time at which the pressure or torque has completed the decrease phase and drops below the noise threshold (typical value 2 bar or 2 daNm);
- ➔ Instant T1S: the time at which the pressure or torque value exceeds a percentage of the value required (typical values 80% and 90% of the final value);
- ➔ Instant T2S: the time at which the reference to the servovalve is reset. The braking control process captures this instant.  
The calculation of the threshold is not used for the final instant in that this could provide incorrect values during constant torque braking. Torque has in fact a slightly delayed trend in relation to pressure; therefore torque is still recorded at the final instant even if pressure is already at zero.
- ➔ Instant T3: the time at which maximum temperature is detected after the end of braking. The maximum temperature is normally obtained a few seconds after completion of braking. The data acquired in this phase are not saved in the time history unless this is explicitly requested using a test programming parameter.
- ➔ Instant T4: the time at which further acquisition made after end of braking terminates. The operator can request continuation of time history acquisition for a time indicated after the end of braking.

In addition to these main instants, there are other instants used for particular types of processing. These are:

- ◆ TMIDDLE Instant: the time that is precisely in the middle of the time between T1S and T2S (half brake application instant); this is used in particular to calculate the half braking friction coefficient;
- ◆ TXTIME Instant: the time specified by the operator as a difference in relation to instant T1S; it is used to calculate the friction coefficient at particular instants of the application (e.g.: after 1 second from reaching 80% of the pressure value).

To calculate instant T1S, the weighted average of the pressure or torque value is used.

The calculation method is as follows:

- ◆ calculation of instants T1 and T2 (exceeding of the noise threshold);
- ◆ calculation of the average value of the pressure or torque channel between instants T1 and T2;

- ◆ calculation of intermediate instants T1P and T2P using the average value obtained in the previous processing as threshold;
- ◆ calculation of the new average value between instants T1P and T2P;
- ◆ repetition of these last 2 operations (calculation of instants T1P and T2P, average value calculation) for the number of times defined in the test rig configuration phase;
- ◆ calculation of instant T1S using the last average value, decreasing this by the percentage set in the test rig configuration phase (typically 80% or 90%).

Processing operations common to all test rigs refer to the four main channels:

- ◆ speed channel;
- ◆ pressure channel;
- ◆ torque channel;
- ◆ pilot thermal-couple temperature.

## List of standard data processing available

The main results present on each test rig are as follows (the units of measurement expressed are those normally used but they are all configurable by the user):

### InstantValue

Calculates the value of a channel at a certain moment. The calculation moment is to be specified in the "**Start moment**" section. If the moment is between two samples, the calculated value is obtained from the interpolation of the previous and subsequent sample. If a processing neighbourhood is defined, the value returned is the MEAN value within the sampling neighbourhood. This formulation is used for example to detect the channel values at the start and the end of the braking, setting as the processing moment **TargetPressure** in the first case and **PressureStop** in the second case

There are 3 possibilities:

1. The moment falls within the sampling time and no processing neighbourhood has been defined.

Value = value at the sampling moment

2. The moment falls between two samplings and no processing neighbourhood has been defined.

The value is the result of interpolation of the value at the previous or the subsequent sampling.

$$V_x = V_1 + (T_x - T_1) \cdot \frac{V_1 - V_2}{T_1 - T_2}$$

T<sub>x</sub> = moment time for which the value is to be found

T<sub>1</sub> = sampling time of the first point

T<sub>2</sub> = sampling time of the second point

V<sub>1</sub> = channel value in the first point

V<sub>2</sub> = channel value in the second point

Example (channel acquired at 50Hz -> period 20 msec) :

T<sub>x</sub> = 0.233 sec

T<sub>1</sub> = 0.220 sec

T<sub>2</sub> = 0.240 sec

V<sub>1</sub> = 4.5 Bar

V<sub>2</sub> = 5.3 Bar

V<sub>x</sub> = 4.5 + (0.233 - 0.220) \* (4.5 - 5.3) / (0.220 - 0.240) = 5.02 Bar

3. A processing neighbourhood is defined.

In this case the value is obtained from the integral between the two times defined by the neighbourhood duration.

$$V_x = \frac{(V_1 + V_0) \circ t_1}{2} + \sum_{i=0}^n \frac{(V_{(i-1)} + V_i) \circ \Delta t}{2} + \frac{(V_n + V_2) \circ \Delta t_2}{2}$$

V1 = value at the start moment of the neighbourhood (interpolated)

V2 = value at the end moment of the neighbourhood (interpolated)

V0 = first sampling value

Vn = last sampling value

$\Delta t_1$  = difference between the time of the start moment and the first sampling

$\Delta t$  = difference between two samplings

$\Delta t_2$  = difference between the time of the end moment and the last sampling

n = number of samplings in the neighbourhood under consideration

### MaxValue

Calculates a channel maximum value between two defined moments.

Value = MAX(Vi, V1 ... Vn, Ve)

Vi = start moment value (interpolated)

Ve = end moment value (interpolated)

V1 ... Vn = Values of the individual samplings between the defined moments, where 'n' is the number of samplings

### MinValue

Calculates a channel minimum value between two defined moments;

Value = MIN(Vi, V1 ... Vn, Ve)

Vi = start moment value (interpolated)

Ve = end moment value (interpolated)

V1 ... Vn = Values of the individual samplings between the defined moments, where 'n' is the number of samplings

### AverageValue

Calculates a channel mean value between two defined moments;

The value is calculated as integral of the area included between the two moments.

$$V_x = \frac{(V_1 + V_0) \circ t_1}{2} + \sum_{i=0}^n \frac{(V_{(i-1)} + V_i) \circ \Delta t}{2} + \frac{(V_n + V_2) \circ \Delta t_2}{2}$$

V1 = start moment value (interpolated)

V2 = end moment value (interpolated)

V0 = first sampling value

Vn = last sampling value

$\Delta t_1$  = difference between the time of the start moment and the first sampling

$\Delta t$  = difference between two samplings

$\Delta t_2$  = difference between the time of the end moment and the last sampling

n = number of samplings in the neighbourhood under consideration

### MaxValueTime

Stores the time at which the maximum value of the reference channel has been read;

### MinValueTime

Stores the time at which the minimum value of the reference channel has been read;

### AverageDeceleration

Calculates the mean deceleration of braking between two defined moments;

The deceleration is calculated with this formula:

$$\delta = \frac{V_i - V_f}{\Delta t}$$

$V_i$  = Speed at the **start** moment [m/sec]

$V_f$  = Speed at the **end** moment [m/sec]

$\Delta t$  = delta time between the start moment and the end moment

### AverageInertia

Calculates the mean inertia of a braking between two defined moments;

The inertia is calculated with this formula:

$$J = \frac{C_m \circ \Delta t}{V_i - V_f}$$

$C_m$  = mean torque [Nm] of the calculation window;

$\Delta t$  = calculation window duration [sec] (end moment time – start moment time);

$V_i$  = Start moment speed [rad/sec];

$V_f$  = End moment speed [rad/sec].

### BrakingDistance

Calculates the distance between the two defined moments;

The braking distance is calculated in two different ways according to the reference channel:

- 1) analog speed channel
- 2) distance incremental counting channel (encoder)

In the first case the braking distance is calculated by means of the speed integral, using this formula:

$$S = \frac{(V_1 + V_0) \circ \Delta t_1}{2} + \sum_{i=0}^n \frac{(V_{(i-1)} + V_i) \circ \Delta t}{2} + \frac{(V_n + V_2) \circ \Delta t_2}{2}$$

$V_1$  = speed [m/sec] at the neighbourhood start moment (interpolated)

$V_2$  = speed [m/sec] at the neighbourhood end moment (interpolated)

$V_0$  = first sampling value [m/sec]

$V_n$  = last sampling value [m/sec]

$\Delta t_1$  = difference between the time of the start moment and the first sampling

$\Delta t$  = difference between two samplings

$\Delta t_2$  = difference between the time of the end moment and the last sampling

$n$  = number of samplings between the start moment and the end moment

In the second case, the distance is calculated as the sum of the individual increases.

$$S = S_0 + \sum_{i=1}^n S_i + S(n+1)$$

$S_0$  = distance value [m] of the first sampling (interpolated) taking into account the  $\Delta t$  between the start time and the time of the first sampling

$S(n+1)$  = distance value [m] of the sampling subsequent to the end time (interpolated) taking into account the  $\Delta t$  between the end time and the time of the last sampling

$S_i$  = distance value of the individual samplings [m]

$n$  = number of samplings between the start moment and the end moment

### AverageEfficiency

Calculates the efficiency of shoe brakes between the two defined moments;

$$Eff = \frac{C_m}{(P - P_{Threshold}) \circ A_{Piston}}$$

$C_m$  = mean torque [Nm] of the calculation window

$P$  = mean pressure [Pa] or [N/m<sup>2</sup>]

$P_{threshold}$  = approach pressure [Pa] or [N/m<sup>2</sup>]

$A_{piston}$  = piston area [m<sup>2</sup>]

### TimeSubtraction

Calculates the time that lapses between two defined moments [sec].

The algebraic difference is found between the calculated time of the START MOMENT configuration and the calculated time of the END MOMENT configuration.

$T = T_{ini} - T_{fine}$  ( $T = StartTime - EndTime$ )

### InstantFriction

Calculates the friction coefficient of a certain moment. With this selection the friction can be calculated at the start of braking, end of braking, a second after 80% of the required value has been reached etc..., changing the calculation modality of the reference moment.

The following formula is used:

$$\mu = \frac{C}{2 \circ (P - P_{Threshold}) \circ A_{Piston} \circ R_{eff} \circ \eta}$$

$C$  = torque [Nm] of the calculation window

$P$  = pressure [Pa or N/m<sup>2</sup>] of the calculation window

$P_{threshold}$  = approach pressure [Pa or N/m<sup>2</sup>]

$A_{piston}$  = piston area [m<sup>2</sup>]

$R_{eff}$  = effective radius [m]

$\eta$  = calliper efficiency

If there is no calculation neighbourhood indicated in the start moment definition, the pressure and torque values are separate values that may be interpolated if they fall between two samplings. If a calculation neighbourhood has been indicated, the pressure and torque values are mean values within the calculation window. The interpolation or calculation modalities for the mean value are the same as those described in the **InstantValue** calculation.

### MaxFriction

Calculates the maximum friction value between two defined moments. The separate friction values are calculated using the pressure and torque values of the individual samplings. The pressure and torque values for the friction calculation at the start moment and the end moment are interpolated.

Calculation formula:

$$\mu = \text{MAX}(\mu_i, \mu_1 \dots \mu_n, \mu_e)$$

$\mu_i$  = friction at start moment

$\mu_e$  = friction at end moment

$\mu_1 \dots \mu_n$  = friction values of individual samplings between the defined moments where 'n' is the number of samplings

### MinFriction

Calculates the minimum friction value between two defined moments. The method for the calculation is the same as for maximum friction.

Calculation formula:

$$\mu = \text{MIN}(\mu_i, \mu_1 \dots \mu_n, \mu_e)$$

$\mu_i$  = friction at start moment

$\mu_e$  = friction at end moment

$\mu_1 \dots \mu_n$  = friction values of individual samplings between the defined moments where 'n' is the number of samplings

### AverageFriction

Calculates the mean friction coefficient between two defined moments. The calculation uses the mean pressure and torque values calculated within the calculation window. The calculation formula is the same as for maximum and minimum friction.

$$\mu = \frac{C}{2 \circ (P - P_{\text{Threshold}}) \circ A_{\text{Piston}} \circ R_{\text{eff}} \circ \eta}$$

C = mean torque [N/m] of the calculation window

P = mean pressure [Pa or N/m<sup>2</sup>] of the calculation window

Pthreshold = approach pressure [Pa or N/m<sup>2</sup>]

Apiston = piston area [m<sup>2</sup>]

Reff = effective radius [m]

η = calliper efficiency

### MaxFrictionTime

Stores the time at which the maximum friction value has been found;

### MinFrictionTime

Stores the time at which the minimum friction value has been found;

### MiddleTimeFriction

Calculates the friction coefficient in the middle point between two defined time instants. The pressure and torque values used are calculated midway between the start moment and the end moment.

$\mu(T)$

$T = T_{\text{ini}} + (T_{\text{fine}} - T_{\text{ini}}) / 2$

Tini = time at start moment

Tfine = time at end moment

### StaticFriction

Calculates the static friction coefficient between two defined moments. It is only used on systems equipped with the device to carry out static tests. The static friction coefficient is the friction coefficient read at the moment when the system passes from a static condition to dynamic condition. At present there is no methodology for an automatic calculation of this change-over, therefore this calculation is not significant.

### InstantTime

Stores the time at the defined moment. The time of the defined moment is stored. This option is useful to carry out post-processing starting from the same calculation moments of the control system.

### StartBrakingTemperature

Stores the start temperature value of the main thermocouple.

### EndBrakingTemperature

Stores the end temperature value of the main thermocouple.

### MaxTemperature

Stores the maximum temperature value of the main thermocouple.

### AveragePower

Calculates the mean specific power between two defined moments. This calculation has been implemented specifically for earthmover brakes (sintered metal brake pads) where the brake has several overlaid friction material disks.

The calculation formula is the following:

$$W = \frac{C \cdot V}{SupTotAttrito}$$

C = mean torque [Nm] of the calculation window

V = mean speed [rad/sec] of the calculation window

SupTotAttrito [mm<sup>2</sup>] (TotalFrictionSurface)

### MaxPower

Calculates the maximum specific power between two defined moments.

This calculation has been implemented specifically for earthmover brakes (sintered metal brake pads) where the brake has several overlaid friction material disks.

The calculation formula is the following:

$$P = \text{MAX}(P_i, P_1 \dots P_n, P_e)$$

$P_i$  = specific power at start moment

$P_e$  = specific power at end moment

$P_1 \dots P_n$  = specific power of the individual samplings between the defined moments, where 'n' is the number of samplings

### Energy

Calculates the specific energy dissipated between two defined moments.

This calculation has been implemented specifically for earthmover brakes (sintered metal brake pads) where the brake has several overlaid friction material disks.

The calculation formula is the following:

$$E_s = PotenzaSpecificaMedia \circ (T_{fine} - T_{ini})$$

PotenzaSpecificaMedia = mean specific power calculated between the defined moments using the previously described formula

Tfine = time of end moment

Tfine = tempo dell'istante iniziale Tini = time of start moment

### InstantSpecPressure

Calculates the specific pressure of a certain moment. In this way the specific pressure in the start/end moments of the braking and in intermediate times can be calculated.

This calculation has been implemented specifically for earthmover brakes (sintered metal brake pads) where the brake has several overlaid friction material disks.

$$P_{spec} = \frac{Pressione \circ SuperficieTotaleAttuatori}{SuperficieAttritoSingolaFaccia}$$

Pressione = Pressure at the defined moment. If a calculation neighbourhood has been specified, the pressure value is the mean of the neighbourhood values. The measure unit remains that selected by the user, it is not indicated in the International System.

SuperficieTotaleAttuatori = indicates the total surface of the actuators in m<sup>2</sup>

SuperficieAttritoSingolaFaccia = indicates the friction surface of a single face of the brake disk pack [m<sup>2</sup>]

### MaxSpecPressure

Calculates the maximum value of the specific pressure between two defined moments. The calculation formula is the same as for the **InstantSpecPressure** calculation

### MinSpecPressure

Calculates the minimum value of the specific pressure between two defined moments. The calculation formula is the same as for the **InstantSpecPressure** calculation.

### AverageSpecPressure

Calculates the mean specific pressure between two defined moments. The calculation formula is the same as for the **InstantSpecPressure** calculation. The pressure value used is the mean value calculated between the two defined moments.

### MathFormula

Calculates the result using an indicated mathematical formula. In the formula all the mathematical operators can be used (+-\*/) and it manages the parentheses levels ((..)..). If the formula is complex, it can be broken down over three lines, Where in the first two, the resulting variable to the left of the equal sign "=" can be used in the following lines. It is also possible to use in the formula the results that have been calculated up to that moment, for example the "Mean Pressure", the "Mean Torque", "Start Speed", etc.. Besides the results also pre-defined key words can be used that identify the characteristics of the brake being tested, such as the piston area, the effective radius, wheel radius, etc.. .

Example of the friction coefficient calculation using results already calculated. The formula is split into three parts.

$$A = CoppiaMedia \text{ (Mean Torque)} * 10$$

$$B = 2 * \text{"Master Cyl Area"} * \text{"Friction Radius"} * ((PressioneMedia(\text{Mean pressure}) - \text{"Approach Pressure"}) * 100000)$$

$$\text{Friction} = A / B$$

Where

- ◆ **A** and **B** are local variables created with the result of the first and second lines
- ◆ **CoppiaMedia (Mean Torque)** and **PressioneMedia (Mean Pressure)** are results that have been calculated beforehand. In the example the CoppiaMedia(Mean Torque) is multiplied by 10 since it is presumed that the result is in **daN\*m** whereas the pressure is multiplied by 100000 since it is presumed that it has been acquired in **bar** whereas in the formula it has to be in Pascal (N/m<sup>2</sup>)
- ◆ **"Master Cyl Area"**, **"Friction Radius"** and **"Approach Pressure "** are internal keywords. The values of these variables are already expressed in the International System.

### FlagMinTemperature

Indicates the first braking following that of the minimum temperature stand-by. This parameter is used only by the specifications supplied by specific customers for tests on FQT machines (Friction Quality Test).

### MiddleFriction

Calculates the value of the median friction coefficient. In statistics the median is the central value of a list of values arranged in increasing order. The reference friction values are the instantaneous friction values.

### ServoTheorValue

Indicates that the servo valve control value is to be entered in the results file. If the braking is checked by pressure, the value is the required pressure value, if it is checked by torque, it is the required torque value, if it is checked in deceleration, the value will be the required deceleration value, not the torque value actuated to obtain the required deceleration.

### StartSpeedTheorValue

Stores the value of the start speed set in the test description file and not the value actually obtained in the test. For example, if it is required to brake starting from 100 km/h, the value of this result is always 100, regardless of the value actually found (99.9, 100.1, 99.2, etc...).

### StartTemperatureTheorValue

Stores the value of the start temperature set in the test description file. As for **StartSpeedTheorValue** also in this case it is the required value and not the actually obtained value.

### RollingStockMeanFriction

Calculates the value of the mean friction coefficient according to the formula applied for the railroad type dynamometers. The friction value is calculated taking into account the distance covered.

$$\mu_m = \left[ \frac{(V_i^2 - V_f^2) \circ m}{2 \circ S_2} - w \right] \circ \frac{R}{r \circ F_b}$$

where:

*V<sub>i</sub>* is the start speed [m/sec]

*V<sub>f</sub>* is the end speed [m/sec]

*m* the weight on a wheel [kg]

*w* dynamometer resistance (for dynamometer with inertia simulation = 0)

*s<sub>2</sub>* is the distance covered to reach 95% of the target value [m]

*R* wheel radius [m]

*r* is the effective radius [m]

*F<sub>b</sub>* mean of the forces of the entire braking arc [N]

## MFDD

Calculates the Mean Fully Developed Deceleration value. This deceleration value is calculated linking the speed to the distance covered. This calculation is similar to that previously described for the friction calculation in rolling stock brake tests, since it is the first term of the formula.

$$dec = \frac{(V_i^2 - V_f^2)}{2s}$$

$$dec = \frac{V_i^2 - V_f^2}{2 \circ s}$$

where:

*Vi* is the start speed [m/sec]

*Vf* is the end speed [m/sec]

*s* is the distance covered between the start speed and the end [m]

The moments that determine the processing window and therefore the values of the start speed, end speed and distance covered, are calculated when the speed value passes over the 80% threshold and 10% of the braking start speed value. For example, if the braking start speed is 80 km/h, the MFDD calculation window is between 64 km/h and 8 km/h. The percentage values to be used in the calculation are defined on the result description screen page, they can be values different from the 80% and 10% used in the example.

## List of special data processing available

The processing that follows is only used if the system is equipped with a noise detector instrument ONO-SOKKI CF350 or CF4220. The interfacing with these instruments is through an RS232 serial line. If these instruments are not installed, the processing is not possible.

### NoiseBraking

Indicates whether the braking that took place surpassed the noise threshold set on the instrument.

### ChnAOnoSokkiFrequency

Frequency where the maximum intensity of noise is found on the data referring to Channel A. The analysis is made on the spectrum of 400 values returned by the instrument.

### ChnAOnoSokkiValue

Maximum noise intensity on the data referring to Channel A. The analysis is made on the spectrum of 400 values returned by the instrument.

### ChnBOnoSokkiFrequency

Frequency where the maximum intensity of noise is found on the data referring to Channel B. The analysis is made on the spectrum of 400 values returned by the instrument.

### ChnBOnoSokkiValue

Maximum noise intensity on the data referring to Channel B. The analysis is made on the spectrum of 400 values returned by the instrument.

### ChnAOnoSokkiValueNoReferenceNoise

Maximum noise intensity with background noise removed, for the data concerning channel A.

### ChnBOnoSokkiValueNoReferenceNoise

Maximum noise intensity with background noise removed, for the data concerning channel B.

### ChnAOnoSokkiFrequencyNoReferenceNoise

Frequency where the maximum intensity of noise is found on the data referring to Channel A. with background noise removed.

### ChnBOnoSokkiFrequencyNoReferenceNoise

Frequency where the maximum intensity of noise is found on the data referring to Channel B. with background noise removed.

## Brake application identification

The numeric results file is organized in table form (CVS text style) and each brake application occupies one line .

The brake applications are identified using the columns specified below.

1. Name of the phase.  
This is the name of the phase to which the brake application performed belongs.
2. Number of events (braking operations effectively performed).  
Identifies the total number of braking operations effectively performed. If there have been no cycle skips or interruptions during the cycle due to exceeding of maximum parameters (deceleration, temperature, pressure, torque), the value contained in this field coincides with that of the progressive braking number.
3. Progressive cycle number.  
This is the number of the progressive cycle being performed also taking into account the various cycle repetition and test repetition loops.
4. Progressive brake application number.  
This is the progressive brake application number being performed also taking into account the various cycle repetition and test repetition loops.
5. Relative cycle number.  
This is the cycle number referring only to the test being performed. It varies in relation to the progressive cycle number in that the current test consists of a set of sequential tests in cascade.
6. Braking number inside the cycle (braking repetition).  
Identifies the repetition number of the braking inside the cycle being performed (e.g.: braking 53 of total 100 braking operations of the cycle).
7. Number of pre-heatings performed.  
This indicates the number of pre-heatings performed before the current braking.
8. DAC TIME  
The time elapsed between a pressure application and the next pressure application.

## Management details of a two-tailstock test rig

The rear and front brake of half a vehicle are tested concurrently on a two-tailstock test rig.

The test rig has two tailstock with two brakes assembled and two servovalves that manage the braking action of the two brakes "in correlation".

It is possible to brake with pressure or torque control on both brakes in all combinations.

The braking action may be independent on the two heads or correlated.

In the case of correlation, one of the heads acts as "master", while the other adapts to the braking action of the first according to a law which may be:

- ◆ a simple pressure (or torque) "cut" to a programmed value;
- ◆ a "cut" depending on deceleration of the vehicle expressed by a polynomial relationship;
- ◆ a diagram, provided to the computer in dots (segments) that expressed rear brake behavior in relation to the front brake.

Particular calculations on the distribution of the braking performed are carried at the end of braking. These are:

- ◆ the torque distribution ratio;
- ◆ the ideal torque distribution ratio;
- ◆ performance;
- ◆ front and rear adherence.

NOTES:

## Details of braking management for comfort tests

After specifying that noise data (recorded by microphones and accelerometers) must be acquired and analyzed using external equipment other than those dedicated to test bed management, certain particular aspects of the hardware e software implemented specifically for the comfort tests are outlined below.

### Hardware

A dedicated communication line with the noise recording equipment is envisaged at bed control level.

This consists of a synchronism relay to provide for example the start and stop of braking and of a serial line or GPIB for transmission (with related protocol) of the data.

The typical dimensions such as pressure, torque, speed and temperature, etc. can be transmitted from the bed control to the noise recording equipment.

To avoid interference, the analog signals transmitted are galvanically insulated.

### Software

The specific aspects of the comfort test software have been divided into two chapters.

The first refers to the communication protocol with the noise recording equipment and any database service to store for example the results of the processing of the individual braking operations that have proved to be noisy.

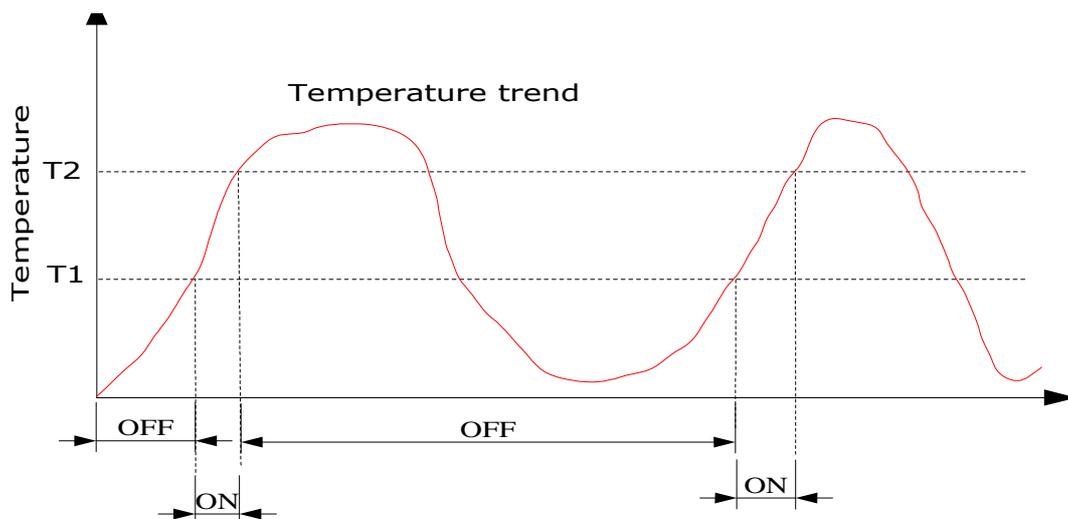
The second includes a different type of braking in order to "scan" the volumes identified by the three axes: temperature, speed and pressure in order to carry out the AK noise matrix test which requires examination of the entire working volume of the brake.

It should also be noted that, generally, noise occurs at low speeds, low pressures and in particular conditions of temperature (and humidity).

## Type of braking for comfort tests

### Braking by temperature ranges

Illustration 15 Braking by temperature ranges in comfort tests



Once the temperature range set by T1 and T2 has stabilized, braking will be carried out within the limits established.

That is to say:

- ◆ if the temperature (identified by one of the four thermal couples) exceeds T2, there is a wait

until temperature T1 is reached with the engine rotating at a speed, defined as parking, set by the operator;

- ◆ if the temperature is below T2, braking is carried out at the programmed speed and pressure;
- ◆ this braking ends: either after a programmed time or on reaching temperature;

Setting a number of repetitions ( $> = 1$ ), the same braking operation is repeated n times.

Arranging various braking operations of this type in sequence in the test program and appropriately modifying the speed and/or pressure values between these, it is possible to "cover" a specific temperature range in various braking conditions.

Putting several temperature ranges in sequence, once again in the test program, it is possible to scan an entire work area of the brake.

### Braking operations according to temperature ranges spaced in time

This type of functioning is similar to that described above with the difference that a programmed period of time must pass between one braking operation and the other.

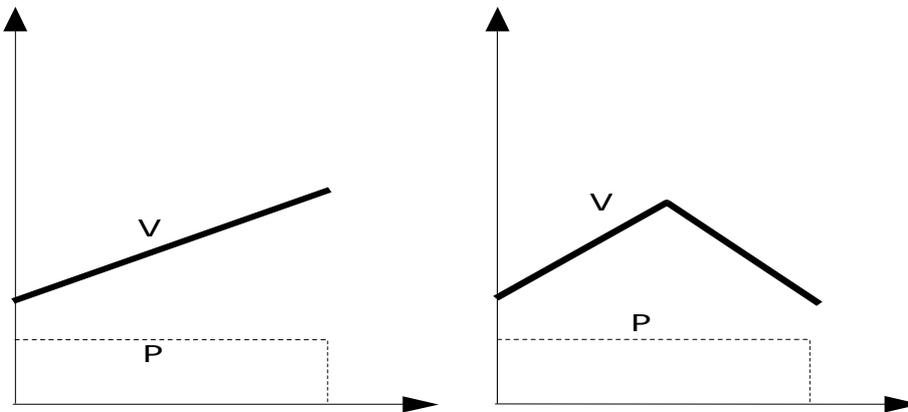
Also, the same braking operation can be repeated:

- ◆ for a programmed number of times;
- ◆ for the number of times necessary to reach temperature T2 (with a maximum programmable safety number).

### Braking operations with speed variation

The pressure is programmed to a fixed value for all braking operations whereas speed is varied in linear mode between the two values programmed.

Illustration 16 Braking operations with speed variation in comfort tests



Speed can also be programmed in increasing or decreasing mode between two values ( $V_{ini}$  and  $V_{fine}$ ) in a time entered, or can be increased and decreased within the same braking operation programming four values:  $V_{ini}$ ,  $V_{med}$ ,  $V_{fine}$  and the total braking time.

### Braking operations with variation of speed spaced in time

This type of functioning is similar to that described above with the difference that a programmed time is left to lapse between one braking operation and the other.

### Braking operations with pressure variation

These are braking operations complementary to the type of braking with speed variation in which, this time, speed is maintained constant and pressure is varied.

### Braking operations with pressure variation spaced in time

This type of functioning is similar to that described above with the difference that a programmed time is left to lapse between one braking operation and the other.

### Cold and hot braking

The braking operations of the types described above may be carried out cold or hot.

In the case of cold braking, two temperatures T1 (minimum) and T2 (maximum) are set and braking operations are carried out if the temperature is below T2.

If the temperature is above T2, there is a wait, at parking speed (programmable) until temperature T1 is reached.

Hot braking operations are carried out starting from the temperature programmed.

This initial temperature is reached: either performing pre-heating or waiting (with the engine rotating) for cooling.

### Direction of travel

Braking operations can be carried out in forwards or reverse.

NOTES:

## Modulated brake assembly ventilation

Brake ventilation is used to simulate what happens on the car in the case in which the brake is cooled by the air that flows over this and which is proportional to the speed of the vehicle.

In order to simulate road behavior, the test rig is equipped with a variable speed fan.

Using an approx. 4 kW 3000 rpm motor, it is possible to obtain ventilation equivalent to that on the Formula 1 vehicle and therefore sufficient to cover all test requirements.

The air from the rotor is channeled to the brake and exhausted by a direction adjustable outlet so as to direct the jet to the area required.

Test rig automation includes various possibilities of fan control.

First of all, ventilation can be enabled or disabled at single braking level and (optionally) also inside the various sections in which braking may be divided.

The control method may be:

- ◆ at fixed speed (programmed);
- ◆ or at a speed proportional to rotation of the flywheel shaft with a programmable ratio.

It is also possible to operate manually during a test and modify ventilation mode from automatic to manual (or vice versa) with the possibility of setting fan speed as required.

In addition to ventilation, on a braking dynamometer, fume extraction must also be provided.

The Buyer usually supplies this system as it is closely tied to the plant engineering of the factory in which the dynamometer is installed.

NOTES:

## Hand brake management

First of all it must be said that complete management of the hand brake is possible only on a dynamometer with the hydraulic motor option.

In fact, the tests usually made on the hand brake are:

- ◆ hot and cold braking capacity test (reaching of specific deceleration values for the vehicle);
- ◆ hold test (hot and cold static friction);
- ◆ "hill hold" type test, that is to say a test to check that a vehicle parked on a hill with the brakes hot does not move as temperature reduces;
- ◆ "creep groan" type test, that is to say checking of noise in creep conditions;
- ◆ and of these, only the first can be carried out without hydraulic motor.

The hardware device designed for hand brake management takes into account all four tests. It consists of:

- ◆ a hydraulic actuator with double stem with different cross-sections and with hydraulic outlet which, if activated, makes it possible to hold the rod still even under force;
- ◆ a load cell;
- ◆ a stroke measurement sensor;
- ◆ a device for adjustment of cable pull (reaction on the sheath).

Test rig automation makes it possible to exchange the braking action from the pump to the cable (or vice versa) during any braking operation of the test cycle in order, for example, to be able to heat the pads and then act on the cable in the case of a duo-servo brake.

The hand brake can be controlled:

- ◆ in torque: pull on the cable is modulated to maintain a constant braking torque;
- ◆ force: pull on the cable is kept constant;
- ◆ position: the stroke of the cable is set to a programmed value and then kept constant;
- ◆ position block: after acting on the cable in force (for example to add a pull of 70 Kg), or in torque or position, the blocking device that maintains the position reached by the cable fixed also under conditions of force.

It should be noted that position control does not provide the same capabilities as the blocking device. It has in fact a precision of approximately one tenth of millimeter and this for example results in oscillations of 15 kg on a force initially set to 70 kg.

NOTES:



- ◆ incremental (programmed) application of a torque by the hydraulic motor until the value corresponding to the gradient of the section of road on which the vehicle is parked is reached;
- ◆ checking, during torque increase, of any slipping and in the case of incipient rotation, increases of the force value on the cable in programmed steps in order to block the start of slipping;
- ◆ further increase (programmed) of force on the cable to reach the torque target;
- ◆ hydraulic blocking of the actuator on the bowden cable;
- ◆ wait for the temperature to drop with checking of slipping.

## Creep groan

Creep groan is the noise generated during application and release of the brake.

Obviously equipment for recording (and analysis) of the noise is required (see [Type of braking for comfort tests](#)).

The creep groan test can also be inserted at any point of the test cycle which means that it can be carried out automatically in various temperature and brake wear conditions.

The procedure comprises the following steps:

- ◆ engagement of the hydraulic motor;
- ◆ application of a high (programmable) pressure (or force) value on the brake so as to guarantee holding of the brake under the action of the torque that will be applied subsequently by the hydraulic motor;
- ◆ application of a torque programmed by the hydraulic motor;
- ◆ automatic search for the point of incipient motion through reduction of the action applied to the brake;
- ◆ application, for a pre-established time, of a sinusoidal modulation (programmed) of the action on the brake in order to cause moments of stop and moments of release.

## Abs simulation

Equipping the test rig with an ABS control unit, it is possible to carry out braking operations with intervention of this regulator.

The conditions on which the braking operations are carried out on the braking dynamometer differ from those on the road. In fact, the vehicle tends to lock the wheels whereas on the test rig, the speed of the disk remains high. The only purpose of this test is therefore to compare the preliminary performance of different braking systems from the point of view of braking space.

The control system, in addition to managing the test rig, sends the ABS control unit the wheel speed simulation.

NOTES:

## Residual torque

For correct measurement of any residual torque, a special system with a sensitivity of 0.2 N\*m and full scale value of 50 - 100 N\*m must be assembled on the test rig.

This measurement system is activated (automatically) at the end of braking at the moment in which the residual torque is to be recorded. This can be recorded both the engine pulling and during natural deceleration.

A special software procedure makes it possible to characterize the test rig through recording of the residual torque ascribable to mechanical friction. This recording may also be made with the pads open.

The value obtained is subtracted from the residual torque curves obtained during the tests.

This procedure is necessary because of the sensitivity of the system and the small residual torque values to be measured.

NOTES:

## Installations made

Without going into details of technological know-how of every installation, a list of the installations made in the last four years with the hardware and software system based on Windows® NT plus DSP for real time management with acquisition and control frequencies of 1 kHz per channel is provided below.

1995 **Fri.Tech.** - Mondovì - CN - Italy

Supply of a new braking dynamometer (with CO.ME.CART. mechanics) with the following characteristics:

- ◆ maximum speed: 2500 rpm;
- ◆ inertia: from 10 to 500 Kgm<sup>2</sup> with 4 flywheel masses and intermediate coverage through inertia simulation (250 kW engine);
- ◆ maximum braking torque: 1000 Kgm;
- ◆ modulated brake ventilation.

The test rig was constructed using a rotating torquemeter (Himmelstein) and permits assembly of the following types of brakes:

- ◆ conventional: with disk on flywheel spindle and caliper on simple saddle type support;
- ◆ with spindle: transmission of motion to the disk by means coupling;
- ◆ entire wheel suspension assy.

1995 - 1996 **S.K. Wellman** - Orzinuovi - BS - Italy

Mechanical overhaul and supply of the automation of a brake test rig in oil bath (for agricultural and construction machinery).

1996 **Ferodo Italiana** - Mondovì - CN - Italy

Replacement of the motors and overhaul of the automation of the two braking dynamometers acquired from FIAT.

The computers of the two test rigs are connected in a network with a server that permits remote management and monitoring.

1996 **ITT Automotive** - Barge - CN - Italy

Update of the mechanics (in cooperation with Stampaf) and overhaul of the automation of braking dynamometer num. 7 adding new capabilities:

- ◆ complete automatic management of the duo-serve with the possibility of braking with the caliper (pressure and torque control) and with the hand brake (pressure and torque control);
- ◆ management of static friction (for pads and shoes) using a hydraulic motor that permits, through automatic engagement (by means of a clutch), application of an increasing torque to the brake until this slips (static friction is calculated correlating the torque that determines the incipient motion in relation to pressure and the force applied to the brake).

- 1996-1997 **Brembo SpA** - Curno - BG - Italy
- Update of the mechanics (in cooperation with Stampaf) and reworking of the automation of the two braking dynamometers acquired from FIAT.
- The electrical motors were replaced (100 kW, 2000 rpm) and installed in axis with the flywheel shaft through coupling with a flexible coupling.
- The torsion bar, for recording of the braking moment, was modified to permit insertion of a quartz type load cell for reading of residual torque.
- To align the test rig with current safety regulations, sliding guards were introduced to cover the brake area. These guards are held in place with electric locks during flywheel rotation.
- The computers of the two test rigs are connected in a network with a server that permits remote management and monitoring.
- 1997 **ITT Automotive** - Barge - CN - Italy
- Overhaul of the automation of the two-test braking dynamometer (num. 2). In cooperation with the Stampaf Company, a general overhaul of the mechanics was carried out replacing the motor and related transmission.
- The test rig is equipped with the following options:
- ◆ braking distribution control;
  - ◆ braking with ABS system.
- 1997 **Brembo SpA** - Curno - BG - Italy
- Retrofitting of the software on the three ESAM automation braking dynamometers. The old PCs (286 and 486) were replaced with Pentium on passive backplane.
- Following this operation, Brembo now has only test rigs with TecSA software.
- 1997 **AP Italia** - Cairo Montenotte - SV - Italy
- Supply of a shoe type brake test rig with useful life, residual torque and static friction tests.
- 1997 **FERODO (now Federal Mogul)** - Mondovì - CN - Italy
- Overhaul of the automation of a small friction test machine adding the volumetric absorption test.
- 1998 **ITT Automotive** - Barge - CN - Italy
- Retrofitting similar to that performed at Brembo, of four braking dynamometers and three small friction test machine.
- Like Brembo, ITT has also used TecSA software on all machines.
- 1998 **Federal Mogul** - Mondovì - CN - Italy
- Addition of the hydraulic motor and hand brake activation device on an existing test rig in order to perform the following tests: hot and cold, with the caliper and with the hand brake:
- ◆ static friction;
  - ◆ creep groan;

◆ hill hold.

Braking is carried out with torque and pressure control for the caliper and control of torque, force and force with subsequent maintenance of the position reached for the hand brake.

1999 **ITT Automotive** - Barge - CN - Italy

"Turn key" supply of a Fast Machine type machine for tests on friction material samples.

The machine is fully automated; similar a real scale braking dynamometer and wet tests can also be carried out.

The mechanics have been produced in cooperation with the Stampaf Company.

1999 **REMSA** - Pamplona - Spain

Supply of a new automotive type braking dynamometer with 160 kgm<sup>2</sup> of inertia and a maximum speed of 2600 rpm.

The rig is now being tested and a Spanish company has produced the mechanical parts.

1999 **Brembo** - Curno - BG - Italy

Variants to two braking dynamometers in order to run comfort (noise) tests and complete overhaul of the automation of a rig used exclusively for comfort tests.

1999 **Federal Mogul (ex Ferodo)** - Mondovì - CN - Italy

Retrofitting of the software on one ESAM braking dynamometer.

The old PC (286) is replaced with the Pentium on the passive backplane.

1999 CRF (Centro Ricerche Fiat) - Orbassano - TO - Italy

Supply of an electrical DC motor control system for research on braking systems.

1999-2000 **ITT -Galfer** - Barge -CN - Italy

Overhaul of the automation of a test rig to which was added a dual drive system to test two brakes simultaneously.

1999-2000 **GAMA** - Ancarano -TE - Italy

"Turn key" supply of a test rig with optional, inertia 200 kg\*m<sup>2</sup> and maximum speed 2500 rpm.

- 2000      **REMSA** – Mexico  
Supply of a new baking dynamometer, with 100 Kg\*m<sup>2</sup> of inertia and maximum speed of 2500 (g/m).  
The mechanical parts have been produced by a Spanish company “Tecner” with supervision TecSA.
- 2000      **ITT- Galfer** .- Barge- CN - Italy  
Addition of an electrical motor and hand brake activation device on an existing test rig in order to perform the following tests: hot and cold, with the caliper and with the hand brake:  
◆ static friction;  
◆ creep groan;  
◆ hill hold.  
With this fitting it is possible to measure the friction coefficient at low rpm: 1-10 rpm.
- 2000      **ITT- Galfer** .- Barge- CN - Italy  
Overhaul of the automation of a two-brake test rig, used to test either truck or train brake. The former system ran on a PDP11.
- 2000      **Rütgers (former FrenDo)** – Atripalda – AV - Italy  
Retrofitting of the software of three ESAM automation braking dynamometer. The old PCs (286 and 488) were replaced with the Pentium on the passive bakplane.
- 2000      **AP Italia** - Cairo Montenotte – SV - Italy  
Overhaul of the automation of an existent test rig, for shoe brake test.
- 2001      **Siffert** – Montefino – TE - Italy  
Overhaul of the automation of an existent test rig with 1800 kg\*m<sup>2</sup> inertia.
- 2001      **Rütgers (formerly FrenDo)** – Orzinuovi BS - Italy  
Overhaul of the automation of an existent friction quality test machine.
- 2001      **ITT- Galfer** – Barge – CN - Italy  
Test rig, with all optional, with the following characteristics: inertia 170 kg\*m<sup>2</sup>, only two flywheels and maximum speed of 2500 rpm.

- 2002      **Union Technique de l'Automobile, du Motorcycle et du Cycle (UTAC)**  
- Montlhéry - Paris - France  
Overhaul of the automation of an existent test rig.
- 2002      **Brembo SpA** - Curno - BG - Italy  
Supply of a test rig to test car and motorbike brakes up to racing class, can achieve speed up to 3200 rpm.
- 2002      **REMSA** - Pamplona - Spain  
Supply of a truck type braking dynamometer with 2700 kgm<sup>2</sup> of inertia and a maximum speed of 1500 rpm, maximum braking torque of 40000 Nm.
- 2002      **REMSA** - Pamplona - Spain  
Supply of a friction quality test machine, with couple up to 2000 Nm fitted with static friction measure and parking brake test assemblies.
- 2002      **Brembo SpA** - Curno - BG - Italy  
Supply of a test rig to test car brakes, can achieve speed up to 2800 rpm, with maximum braking torque of 5000 Nm.
- 2002      **AP Italia** - Cairo Montenotte - SV - Italy  
Mechanical overhaul and supply of the automation of a car brake test rig.

NOTES:



