

SUSPENSION

Hydractive

CITROËN

PREFACE

The equipment linking a vehicle's body to the ground is of fundamental importance for the safety and comfort of its occupants. And from the earliest sedan chair – when running gear was most aptly named – to the Formula 1 racing car, automotive engineers have constantly sought to find ways of improving suspension.

Citroën has a long-standing involvement in this area of vehicle design, and the extensive research the firm has led – particularly since the days of the Traction Avant – has brought many tangible results. Indeed, progress in the field of suspension has become a sort of technical tradition and the standard-bearer of Citroën's pioneering image. Applying the discoveries of two 17th century scientists – Blaise Pascal, who proved that a fluid transmits external pressure equally in all directions, and Edme Mariotte, who demonstrated that the volume of a gas times its pressure is constant at fixed tem-

perature – Citroën engineers were able to meet two formerly contradictory objectives: comfort and road holding capacity. The launch of the DS marked a significant milestone in the history of suspension. Rather than relying solely on mechanical systems, Citroën's DS also applied the laws of fluid mechanics to achieve maximum spring, gentle damping and constant ground clearance irrespective of vehicle payload.

Almost immediately afterwards, in the 1950s, Citroën filed a patent for a suspension system that used radar to detect irregularities on the ground. This was the first step towards "intelligent" suspension, where running gear is capable of reacting automatically to changes in road surfaces. Today, Citroën's microprocessor-controlled hydraulic suspension system, which relies on sensors installed at different points on the vehicle, can optimize automotive suspension and has opened a new chapter in the history of the automobile, where technology serves the dual ends of safety and comfort.

Jacques Wolgensinger.

CONTENTS

PREFACE 1

AUTOMOBILE SUSPENSION 3

Basic definitions
A difficult compromise

HYDRAULIC SUSPENSION 5

Laws of fluid mechanics
How hydraulic suspension works
A new chapter

HYDRACTIVE SUSPENSION 7

Two suspension modes
Basic principles
On-board computer and sensors
Anticipating the vehicle's reactions
Three spheres and four dampers
Modular suspension system
Hydraulic functions
Firm system
Soft system
Electronic control
Sensors
Manual mode selection
Front suspension

CONCLUSION 19

AUTOMOBILE SUSPENSION

The basic functions of automobile suspension are as follows:

- allowing the wheels to follow ground relief without transmitting excessive strain to the body;
- ensuring the wheels remain in contact with the ground;
- minimizing movements of the suspended assembly, and particularly the passenger compartment.

Suspension basically involves the combined action of springs and dampers.

Basic definitions

In order to absorb or reduce shocks and vibration caused by irregularities of the surface on which the car is moving, a spring or elastic assembly must be fitted between the wheel and the body.

In order to ensure that these shocks and vibrations are absorbed effectively, the suspension must be highly flexible.

But irregularities tend to make the wheels jump off the road surface and to cause the vehicle to rock – and this rocking has a negative effect on road holding. The softer the springs are, the more pronounced this rocking will be, and it is the damper's role to control the rocking motion. The damper has a dual objective: to overcome the rocking

motion of the body, and to keep the wheels in contact with the ground.

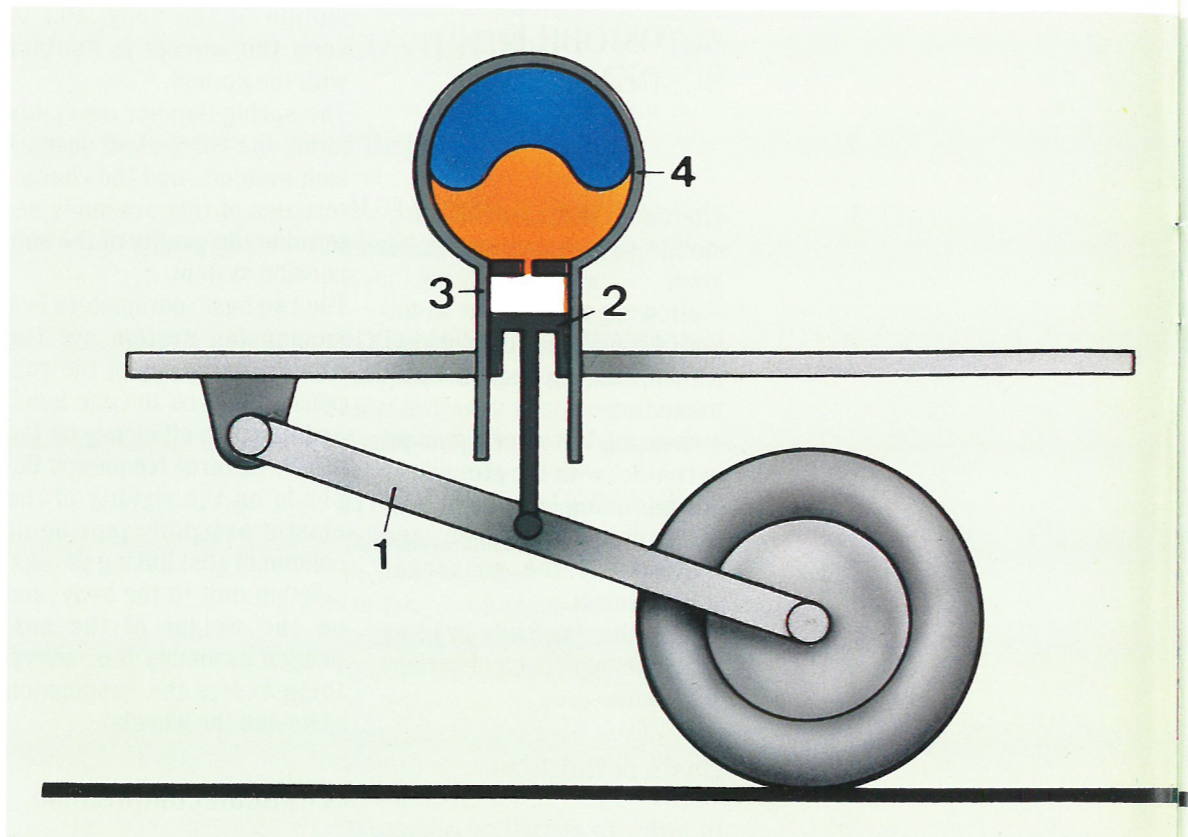
The spring-damper assembly forms the basis of all suspension systems, and the characteristics of this assembly determine the quality of the suspension system.

The two basic parameters in a suspension system are the natural frequency of the suspension unit on the one hand, and damping efficiency on the other. Natural frequency depends on the rigidity of the elastic assembly (spring or column of gas) linking the suspension unit to the body, and on the weight of the suspended assembly (i.e., everything except the suspension units and the wheels).

A difficult compromise

The most comfortable ride is achieved with soft suspension and gentle damping, while maximum road holding capacity is obtained with firmer suspension and heavier damping.

Traditional suspension systems cannot balance these two requirements dynamically, and designers are thus faced with a choice. However cleverly they may be engineered, traditional suspension systems are a compromise. Electronically controlled hydraulic suspension, on the other hand, constantly optimizes spring and damping in line with road conditions and driving style.



Hydraulic suspension

Principle of operation

1. Suspension arm
2. Piston
3. Cylinder
4. Sphere

HYDRAULIC SUSPENSION

In hydraulic suspension, traditional mechanical springs are replaced by two fluids: mineral oil and nitrogen gas.

Laws of fluid mechanics

The behaviour of gases and liquids are governed by the following laws:

- **Pascal's law:** fluids at rest integrally transmit externally applied pressure equally in all directions;
- **Mariotte's law:** the product of the volume of a gas times

its pressure is constant at fixed temperature, i.e., $P \times V = K$ (constant);

– **Laplace's equation:** in fluid dynamics, when the temperature of a gas varies, $P \times V^\gamma = K$ (constant), where γ is a coefficient for a given gas ($\gamma = 1.4$ for nitrogen).

How hydraulic suspension works

In hydraulic suspension, elasticity is provided by a gas, and gas pressure varies in proportion to the load applied. The liquid (which, like all liquids, is incompressible) forms the interface between the gas and the moving parts on the suspension unit.

Each wheel is independent and is linked to the body by a suspension arm (1). A piston (2) fixed to this suspension arm moves inside a cylinder (3) and transmits energy through a membrane to a liquid. The liquid in turn compresses a constant mass of gas contained in a steel sphere (4).

The mass of gas in the sphere does not vary, and the flexibility of this pneumatic spring is proportional to its pressure and its volume ($P \times V^\gamma = K$).

Hydraulic suspension allows for greater flexibility and constant ground clearance under all loads. An automatic compensation device varies the volume of liquid to keep the height of the vehicle constant when the vehicle's payload changes.

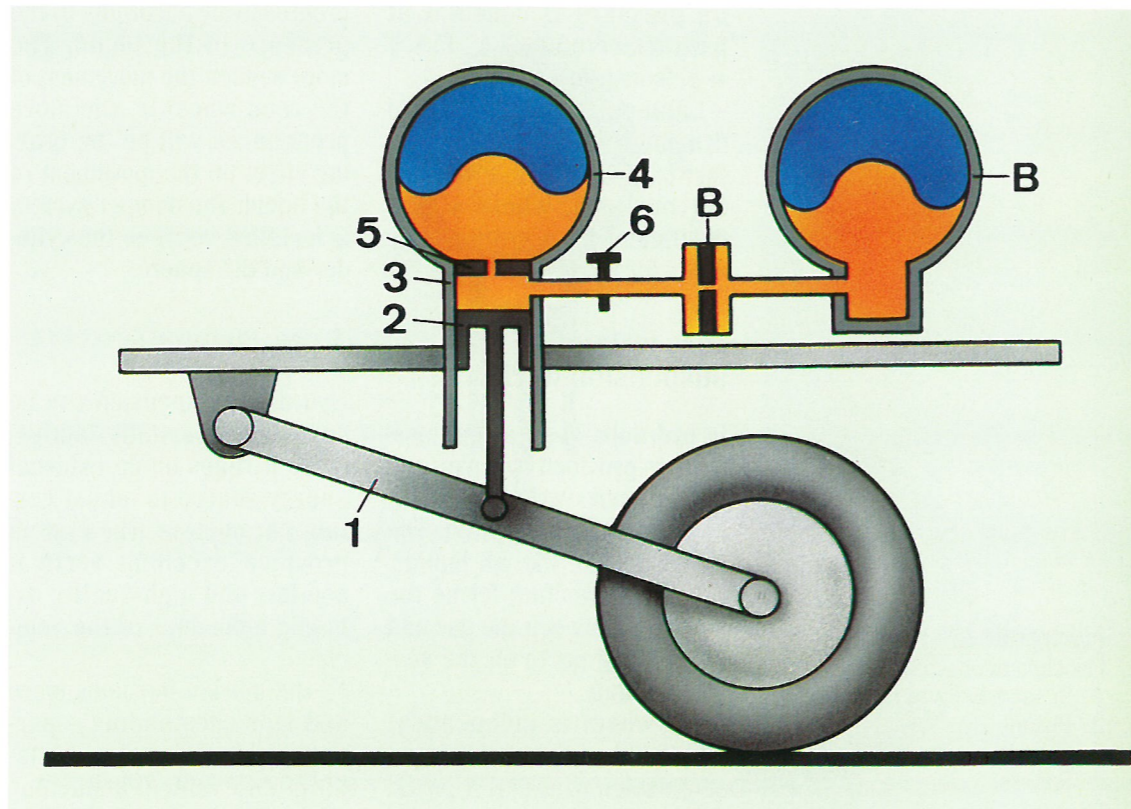
Damping is achieved by allowing a carefully measured volume of liquid to escape through orifices fitted with valves that open and close

progressively according to the pressure in the liquid. The more sudden the movement of the road wheel is, the more pronounced will be the braking effect on the movement of the liquid. The damper system is installed between the cylinder and the sphere.

A new chapter

Hydraulic suspension can be considered partially "active" since it relies on an external energy source to adjust certain parameters. The system provides excellent vertical comfort and high-quality dynamic behaviour of the vehicle.

As the market becomes more and more demanding – particularly in terms of body stability and vehicle behaviour during cornering – Citroën has now crossed a new frontier in hydraulic suspension. The findings of recent R & D work into active systems and the latest possibilities of advanced electronics have now allowed the firm to take its new concepts into the industrial phase.

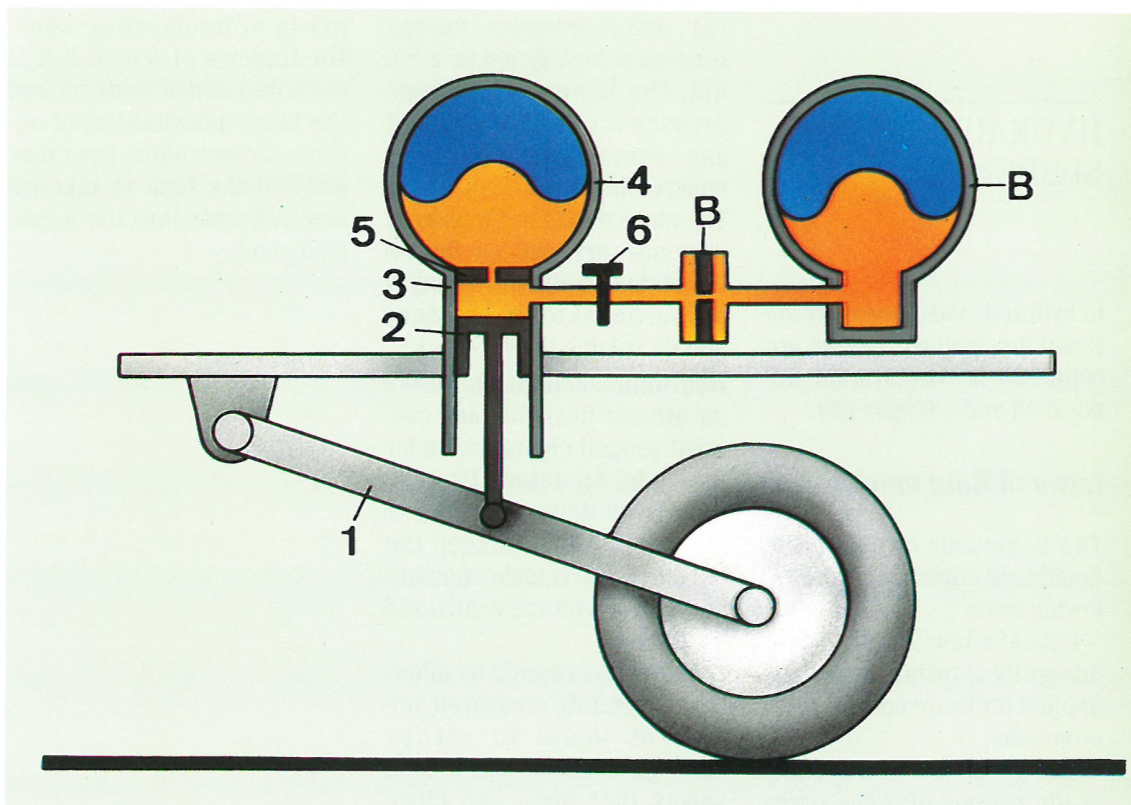


Hydractive suspension

Basic principles

Soft mode

- 1. Suspension arm
- 2. Piston
- 3. Cylinder
- 4. Sphere
- 5. Damper
- 6. Regulator (open)
- B. Additional sphere and damper



Hydractive suspension

Basic principles

Firm mode

- 1. Suspension arm
- 2. Piston
- 3. Cylinder
- 4. Sphere
- 5. Damper
- 6. Regulator (closed)
- B. Additional sphere and damper

HYDRACTIVE SUSPENSION

The ideal automobile suspension system would be "intelligent", that is, capable of constantly taking external conditions and driver behaviour into account to optimize comfort and driving pleasure at the same time as enhancing road holding capacity and increasing active safety.

Two suspension modes

Through the association of two technologies – high-pressure hydraulics and on-board electronics – Citroën has developed a smart suspension system that reconciles all these goals. The hydractive suspension of the new Citroën XM offers two suspension modes:

- **Soft mode** offers optimum comfort and driving pleasure, and is selected for an average of 85% of total driving time. In soft mode, suspension is highly flexible and damping is low, thereby insulating the passengers from shocks and vibrations caused by the road surface.

- **Firm mode** guarantees top-quality road behaviour and maximum active safety, and is selected for an average of 15% of total driving time. In firm mode, the suspension is less flexible and the level of damping is higher, thereby reducing the negative effects of roll (1), pitch (2), yaw (3), pumping (4) and bottoming (5) on rough road surfaces.

Basic principles

Diagrams show a hydraulic suspension unit with sphere B and damper B. When flexibility is raised by increasing the volume of nitrogen, and damping is reduced by allowing oil to escape through both orifices, soft mode is achieved.

To achieve firm mode, a regulator isolates damper B. The volume of nitrogen is reduced, flexibility falls, and oil escapes through a single orifice, which increases the damping effect.

On-board computer and sensors

Hydractive suspension is controlled by a microprocessor, which instantly and automatically adjusts suspension settings (soft or firm) in order to anticipate the vehicle's reactions to driver behaviour and road conditions.

This on-board computer is connected to five sensors and uses the data it receives from

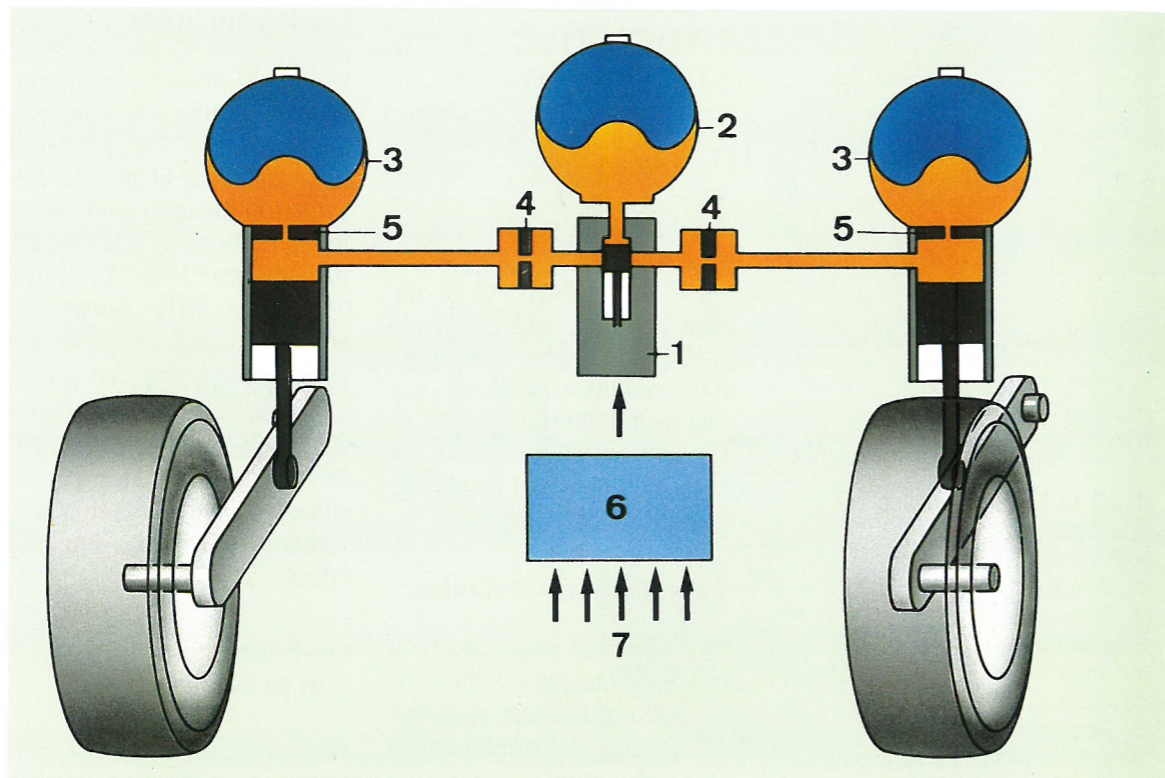
(1) Roll: rotational or oscillatory movement of the suspended assembly of a vehicle about a longitudinal axis through the body.

(2) Pitch: rising and falling motion of the suspended assembly about a transverse axis.

(3) Yaw: rotational or oscillatory movement of a vehicle around a vertical axis passing through its centre of gravity.

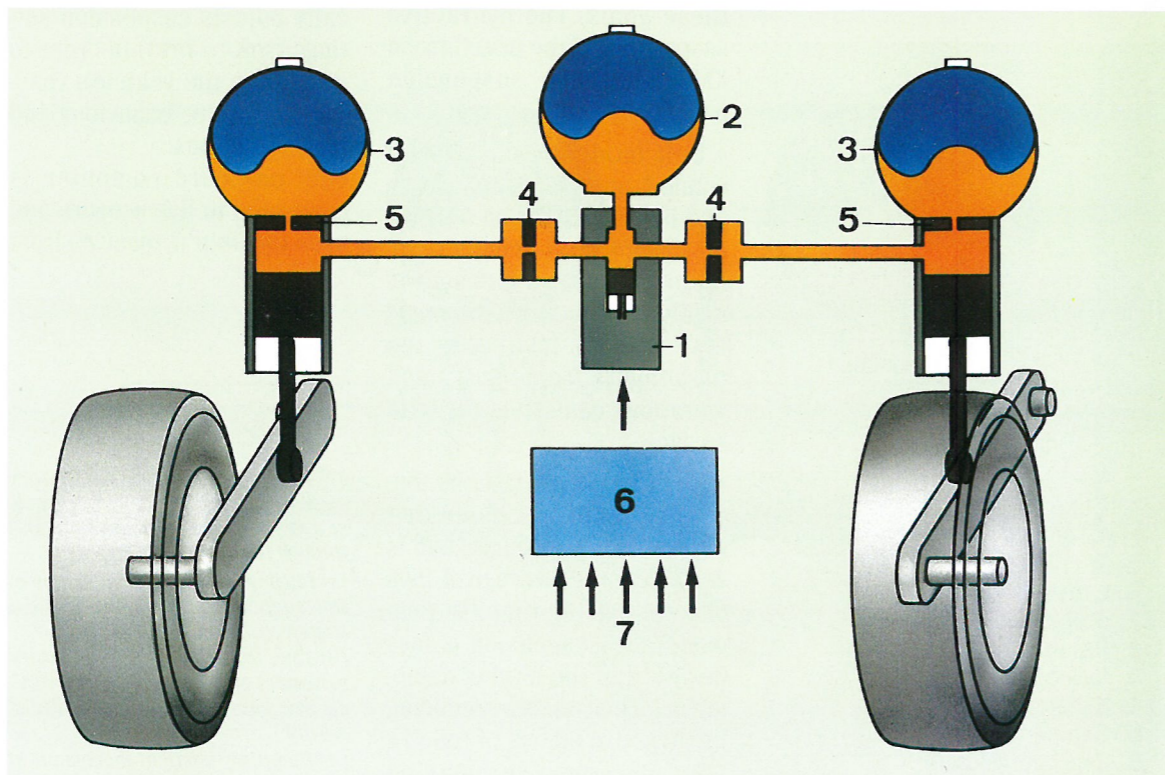
(4) Pumping: vertical movement of the suspended assembly.

(5) Bottoming: sudden contact with a fixed point.



Hydractive suspension
Basic principles of suspension unit
Firm mode

1. Firmness regulator
2. Additional sphere
3. Main spheres
4. Additional dampers
5. Main dampers
6. Computer
7. Sensors



Hydractive suspension
Basic principles of suspension unit
Soft mode

1. Firmness regulator
2. Additional sphere
3. Main spheres
4. Additional dampers
5. Main dampers
6. Computer
7. Sensors

those sensors to control the firmness regulator. The sensors are as follows:

- 1 – one sensor on the steering wheel to measure steering-wheel angle and angular velocity;
- 2 – one sensor on the accelerator to measure the speed of movement of the accelerator pedal;
- 3 – one sensor to measure pressure in the brake circuit;
- 4 – one sensor on the front anti-roll bar to measure amplitude and speed of body movements;
- 5 – one sensor on the gearbox to measure vehicle speed.

Anticipating the vehicle's reactions

Sensor data is compared constantly with the laws stored in the computer's memory, and, depending on the results, the computer instantly selects the most suitable suspension mode. Global response time is less than 0.05 seconds.

The type of information the sensors send to the computer is such that the system always acts in advance of the dynamic reactions of the vehicle. This forward-looking approach is particularly beneficial when driving fast on winding roads: it overcomes sudden movements of the body and significantly enhances the dynamic behaviour of the vehicle.

Three spheres and four dampers

Instead of the two spheres and two dampers that are stan-

dard on hydraulic suspension units, hydractive suspension has three spheres and four dampers. The additional sphere is used to modify the amount of gas in the suspension unit and thus to vary flexibility.

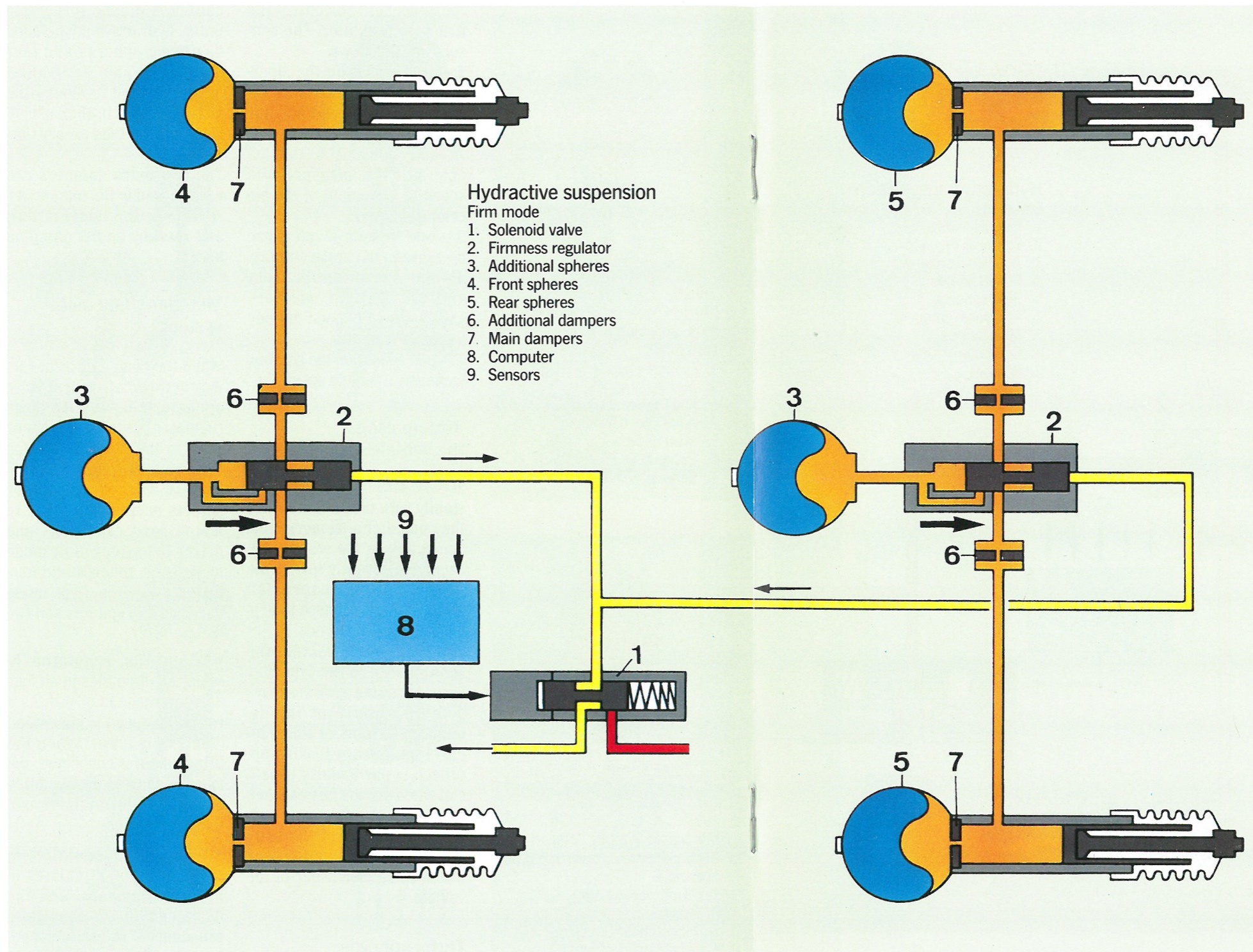
The two extra dampers are used to modify the total cross-section of the liquid circuit and thereby adjust damping level.

Modular suspension system

When the computer issues its instructions, a solenoid valve opens or closes a firmness regulator, which connects or isolates the third sphere and the two additional dampers. In this way, the computer selects suspension mode to match road conditions and driver behaviour. Soft mode uses three spheres and four dampers, while firm mode uses just two spheres and two dampers.

- **When the regulator is open**, oil circulates in all four dampers instead of two. As a result, oil speed is higher and damping is lower. When the third sphere is connected, the mass of gas and the flexibility of the suspension increase: this is soft mode.

- **When the regulator is closed**, the oil circulates in just two dampers, and the damping effect is thus more pronounced. The third sphere is isolated, the mass of gas decreases, and flexibility is reduced to achieve firm mode.



Hydraulic functions

The hydraulic functions of the XM hydractive suspension system are performed by the following equipment:

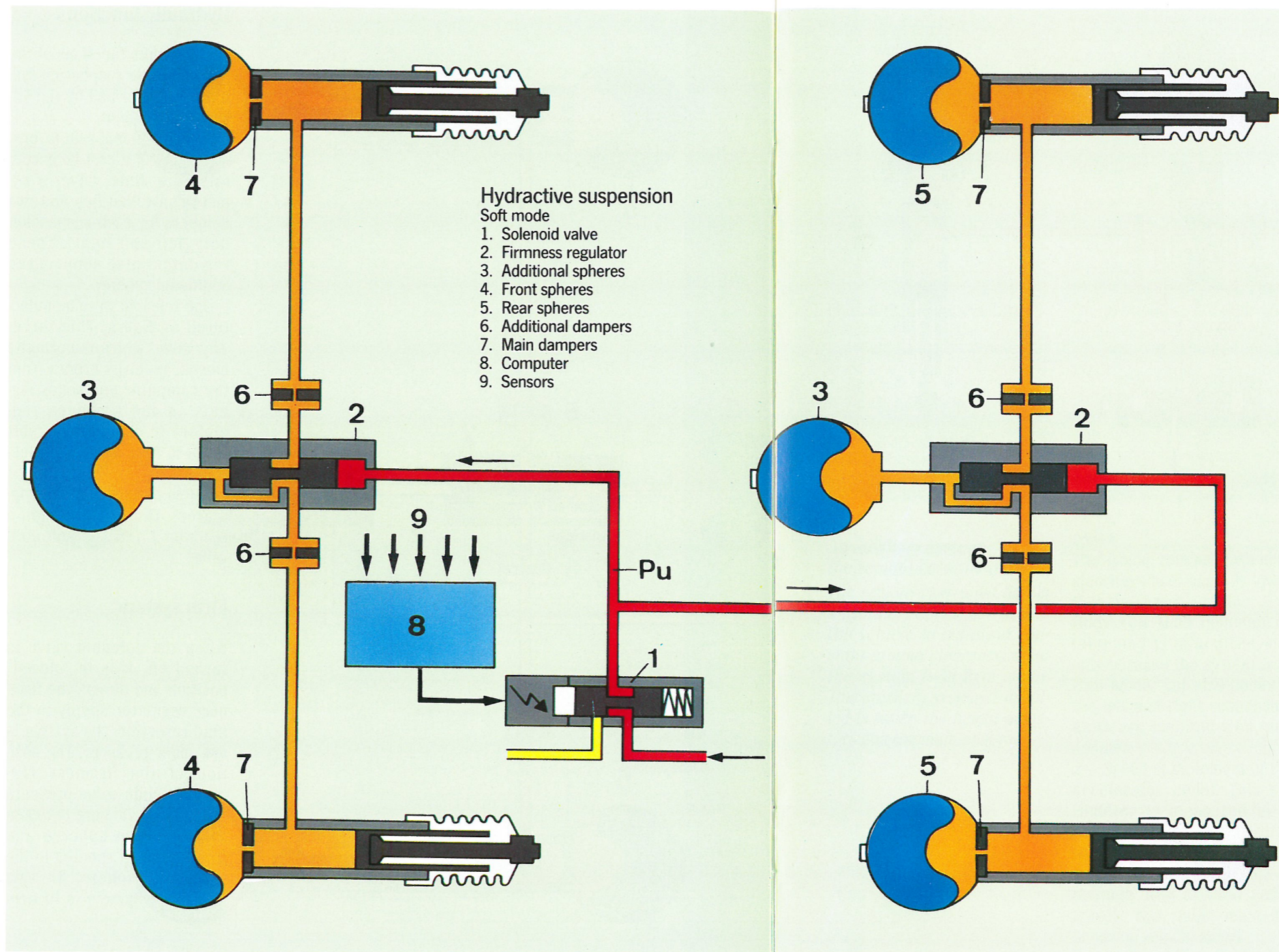
- Two firmness regulators, consisting of a cast body containing a slide valve, a remote-controlled flap and two dampers for each suspension unit (left and right). These regulators also support the additional sphere;

- One solenoid valve manufactured by Eaton. This three-way valve, which is normally closed, receives orders from the computer and sends signals to the firmness regulators to change from soft mode to firm mode and vice-versa;

- Tubes connecting the regulators to the suspension cylinders and the solenoid valve.

Firm system

When the solenoid valve is turned off, it is in "closed" position and directs the firmness regulator supply to the fluid reservoir: the system is not under pressure. The position of the firmness regulator's slide valve prevents liquid from flowing between the two main spheres and from the main spheres to the additional sphere. In this state, the system is in firm mode.



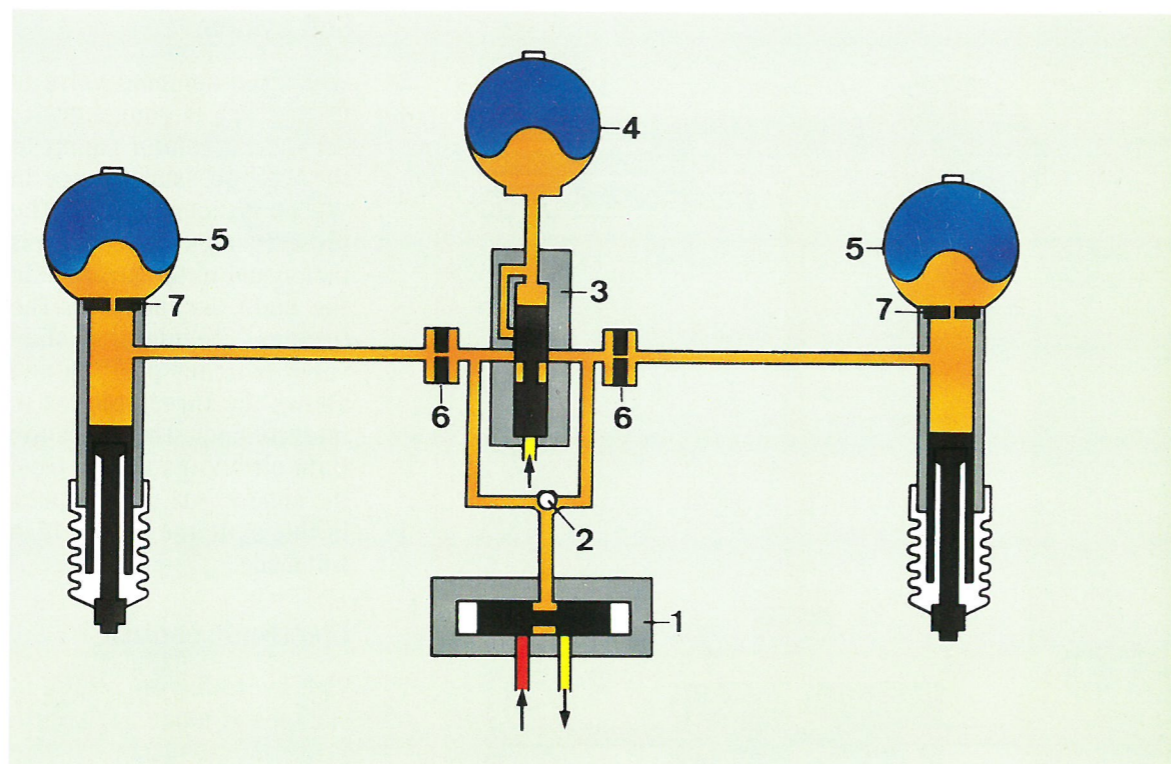
Soft system

When the solenoid valve is turned on, it connects the firmness regulator supply to the high-pressure source in the main accumulator. The pressure in the system (P_u) is then equal to the pressure in the main accumulator. The firmness regulator's slide valve switches position and allows the three spheres to interconnect. The hydraulic fluid circulates to and from the spheres via the dampers. In this state the system is in soft mode.

Electronic control

The hydraulic system and changes of mode are micro-processor-controlled. The computer compares data from the sensors with laws programmed in its memory, and correlates data from different sources to check that the system is operating correctly. If an anomaly is detected, the computer automatically switches the system to firm mode.

The laws used to program the computer were developed after extensive experimentation. Various CX owners agreed to test a very similar suspension system on their cars, and the data gathered from the hundreds of thousands of kilometers they drove was carefully examined and cross-checked. The hydractive suspension system



Hydractive suspension

- Remote-controlled flap
1. Height correction device
 2. Remote-controlled flap
 3. Firmness regulator
 4. Additional sphere
 5. Main spheres
 6. Additional dampers
 7. Main dampers

An auxiliary system: the remote controlled flap

The remote-controlled flap is a hydraulic device that allows the vehicle to maintain constant ground clearance when the system is in firm mode. This auxiliary system is installed between the height adjusters and the main spheres.

that was ultimately developed owes its outstanding performance to the accuracy of these laws and to their ability to match real driving conditions.

Sensors

Five on-board sensors send data to the computer on the following parameters:

1 – Angle and angular speed of the steering wheel. These two parameters are measured by an opto-electronic sensor (6), which is mounted on the steering column opposite a slotted wheel driven by the steering shaft.

The system switches to firm mode when the steering wheel angle or angular speed reaches a set value, which varies in line with vehicle speed.

The system remains firm until steering wheel angle is lower than the threshold value.

Body roll thus commences later and is minimized, not only because the system is in firm mode, but also because the left and right suspension units are isolated from one another.

2 – Speed of movement of the accelerator pedal. This parameter is measured by a potentiometer, which records the time the pedal takes to move in either direction through 10% of total pedal travel. The range used depends on vehicle speed.

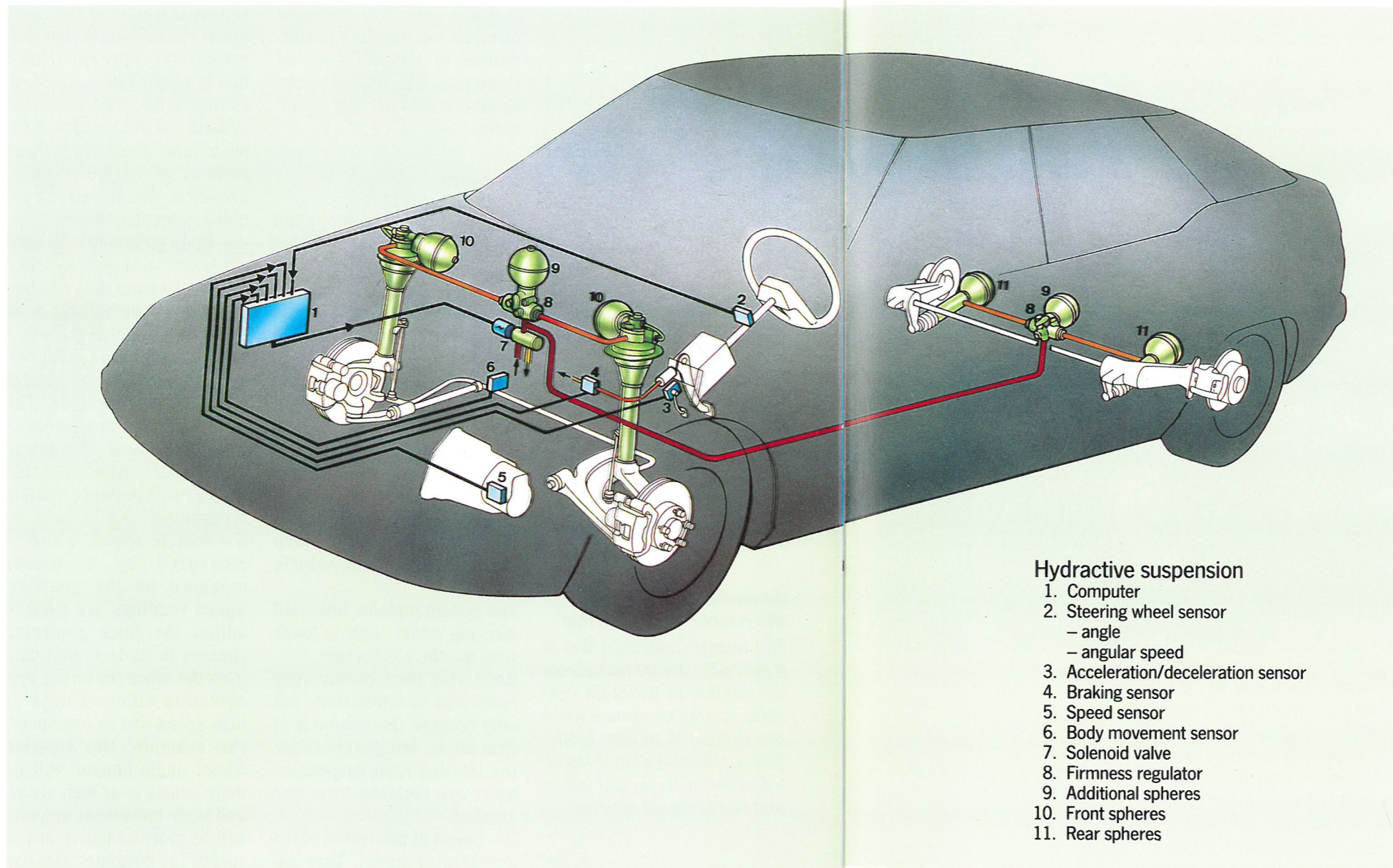
3 – Braking effort. Braking effort is measured by a pressure

sensor installed in the front brake circuit. When this sensor detects a pressure level that is higher than a given reference value, the suspension system switches into firm mode and remains in that state as the car decelerates, provided deceleration exceeds a threshold value.

4 – Body movement. An optical sensor measures the rotation of the front anti-roll bar. As soon as the amplitude of the body movement exceeds a given threshold in compression or rebound, the system switches to firm mode. The speed of body movement is also taken into account to avoid sudden movements that would inconvenience vehicle occupants.

5 – Vehicle speed, which is measured by a sensor mounted on the gearbox. Speed readings are used to adjust the laws governing changes in mode so that data from the other sensors is processed in different ways at high speed and at low speed. For example, the steering wheel angle sensor will be more sensitive at high speed, and body movement sensors will be more sensitive at low speed. The computer also calculates the real acceleration or deceleration of the vehicle in order to correlate data from braking and acceleration sensors.

(6) Opto-electronic sensor: electronically controlled optical sensor.



Hydractive suspension

1. Computer
2. Steering wheel sensor
– angle
– angular speed
3. Acceleration/deceleration sensor
4. Braking sensor
5. Speed sensor
6. Body movement sensor
7. Solenoid valve
8. Firmness regulator
9. Additional spheres
10. Front spheres
11. Rear spheres

Manual mode selection

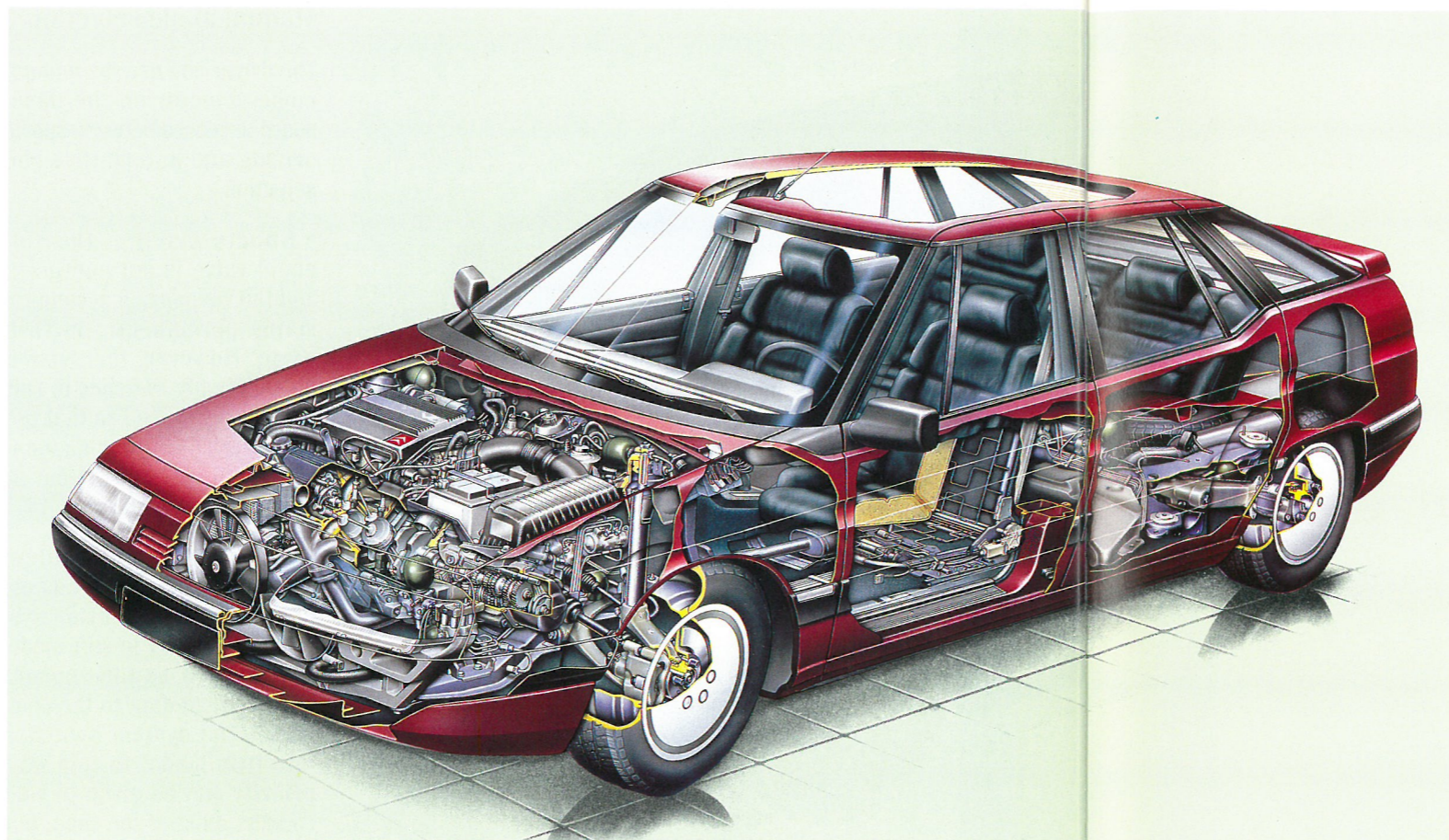
The driver can use the manual mode selector on the dashboard to choose between sports driving and automatic mode selection.

- **Sports driving:** the solenoid valve is not energized and the suspension system remains permanently in firm mode. However, the system automatically switches to soft mode at low speed so that the pressure in all four suspension units can balance out at the beginning of the trip.

- **Automatic mode selection:** the solenoid valve is energized. The suspension system is normally in soft mode, but as soon as the sensors relay critical data to the computer, the system switches into firm mode. In this way, priority can be given to ride comfort most of the time, but as soon as the sensors detect changes such as sudden steering wheel movements, acceleration, deceleration or humps in the road, firm mode temporarily comes into operation to offer better control of body movements and enhanced occupant safety. As a result of the system's capacity to anticipate the vehicle's dynamic reactions, and the speed with which it reacts to sensor signals, the driver is entirely unaware of changes of mode.

Front suspension

To make the most of the possibilities of hydractive suspen-



sion, very close attention has been paid to the front suspension unit of the XM, and two features in particular have a direct influence on the vehicle's behaviour on the road.

The left and right linkages are carried on a subframe that is attached to the front of the body at four points. The lower arms are in forged steel and form wide-based wishbones to provide accurate geometry. Rubber bushes locating the wishbones on the subframe absorb horizontal vibration, while vertical vibration is filtered out by the upper mounting of the strut.

The two modifications that have been made to the suspension unit involve this strut:

- the special layout of the upper part of the strut assembly reduces internal friction so that a hydraulic force opposes any lateral force that may be applied to the suspension unit;

- a progressive-action hydraulic stop avoids bottoming when the vehicle is driven over humps in the road.

The overall performance of the front suspension has been improved. The anti-roll bar is directly connected by rods to the strut rather than to the suspension arm. The bar is thus more effective and reacts more quickly, because the direct link saves the time that would be needed to compress the rubber mounting bushes of the suspension arm. In addition, these mounting bushes absorb vibration more effectively and are more capable of performing their main functions of isolation and articulation, especially during large wheel movements.

CONCLUSION

There is a growing tendency to speak of intelligent suspension even though most of these systems are only capable of modulating damping. The hydractive suspension of the Citroën XM is the only hydraulic suspension system that can instantly vary both spring and damping at the same time as maintaining constant ground clearance.

Switching between soft mode and firm mode in a fraction of a second, the intelligent suspension system of the XM combines driving pleasure and comfort with unparalleled road holding and active safety.

The qualities of this new suspension system further enhance the recognized benefits of Citroën's hydraulic suspension:

- constant ground clearance irrespective of vehicle payload;
- constant suspension qualities and drag coefficient at all loads;
- driver-controlled vehicle height for difficult terrain;
- dampers integrated in suspension system for absolute dependability and reduced wear factors;
- minimum maintenance requirements.

True to its tradition as a pioneer of technology, Citroën has taken a significant lead in yet another area of automotive engineering. With the hydractive suspension system of its new XM, Citroën has moved the industry forward in its quest to solve the major problem facing land-mobile vehicles.

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