Hydractive 2 suspension system

In comparison to a regular hydropneumatic suspension, Hydractive 2 adds the following elements:

1) Additional hydraulic elements (compared to hydropneumatic):
- Two additional spheres with no damping elements (similar to accumulator spheres), one for the front wheels, and one for the rear wheels.
- Two electro-hydraulically controlled suspension control blocks, which fit the spheres above, again one for the front wheels and one for the back wheels.
The control blocks connect the left and right corner sphere and the height corrector, and depending on the electric control, the center sphere. This enables the suspension to have two spring/damping settings, which can be quickly selected by an electric signal. The suspension has a soft setting with low resonance frequency, and a hard suspension setting with a higher resonance frequency. The roll characteristics of the suspension also change depending on suspension setting. In hard mode the cross-flow of fluid between left and right corner spheres is severely limited. This considerably dampens rolling motion. In the soft setting the fluid passes through the double damper element arrangement. The roll motion damping of the suspension is significantly lower than for the hard setting.

2) Electronic sub-system:
- A set of sensors that sense the dynamics of the vehicle
- A user command input enables the driver to choose the suspension mode between 'normal' and 'sport'
- An ECU (Electronic Control Unit) that uses the inputs from the sensor and the user select input to generate the control signal for the suspension control block, and a status signal for the user
- A suspension status light on the dashboard that tells the driver which setting is selected
The ECU reacts to inputs from it's sensors to dynamically select the soft or hard mode of the suspension, based on two sets of rules, one each for the normal and sport suspension setting. The ECU uses a relatively simple but effective set of rules to be able to decide on the suspension setting within 25ms.

Hydraulic elements

1) Suspension control block
The suspension control block consists of several distinct elements:
- A standard Citroen sphere base which fits an accumulator type sphere (without a damper block)
- A hydraulically controlled valve that connects or isolates the sphere above from the rest of the suspension circuit, in effect, a 'control piston' within the control block.
- A ball and piston valve arrangement that limits fluid cross-flow between the left and right suspension strut. The arrangement is such that the ball valve limits cross flow, but is disabled for suspension height corrections, to guarantee that the fluid pressure in the corner struts remains equalized.
- Two damping elements similar to the ones used on suspension spheres, that act as dampers for the center sphere.
The suspension control blocks for the front and rear suspension are the same.
The picture below shows the suspension control block, with the electric valve already mounted.
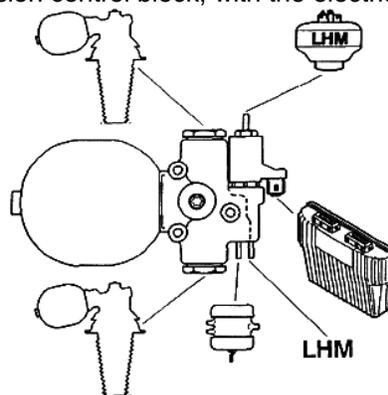
2) Electrically controlled valve

The valve is located on the suspension control block and is driven by the ECU. It's resistance is 4 ohms and the nominal voltage, for continuous duty is 2.6V. However, due to the inductance of the winding, the ECU uses pulse width modulation to achieve a constant current through the winding. This makes the valve react quicker by increasing the drive voltage when it is turned on, but also reduces heat buildup since the voltage reduces once the inductive effects have been overcome, should the valve stay on for a long enough time. The valve is designed to be on indefinitely as long as the proper current is driven through it. The cross-section of the valve is shown below:
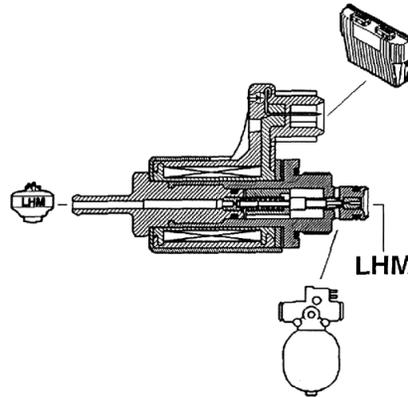
The valve itself does NOT control the flow of fluid into the center sphere. instead, it controls the fluid flow to the hydraulically controlled valve inside the suspension control block body. The valve enables passage of the main feed pressure from the main feed to the control piston located within the control block (orifice marked LHM to orifice marked with the control block outline in the picture above), or it enables the pressure activating the control piston to escape through a simple non-return valve through the valve body (to the orifice marked with the LHM tank outline in the picture above). In this way the valve actually only controls the control piston, in effect implementing an electro-hydraulic relay of sorts.

The electric portion of the valve is energized when the suspension is in it's SOFT setting. Electrically, the default position of the suspension is HARD. However, due to the indirect action of the suspension valve within the suspension regulator body, depending on the suspension pressure and the pressure in the main feed, with the electric valve disconnected, the suspension can remain in either position for extended periods of time. With the main suspension pressure feed at nominal pressure, both the electric and the hydraulic part of the valve will remain in HARD mode.

3) The center sphere

The center sphere is an accumulator type sphere that is used to provide a lowering of the spring constant of the suspension when the sphere is connected to the rest of the suspension circuit. The spheres differ depending on the vehicle version and also depending on weather they are used for the front or rear suspension.
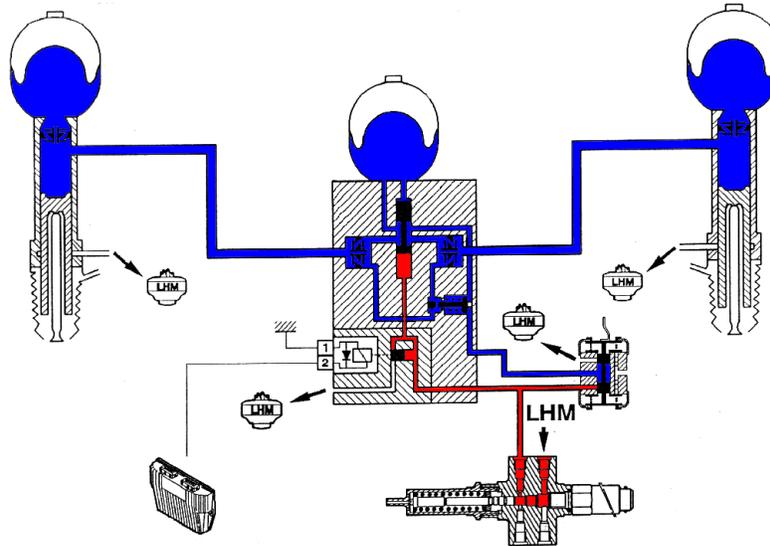
The picture above depicts the soft setting of the control block. The blue areas are LHM fluid under suspension pressure, the red area is the suspension hydraulics feed, under the system feed pressure (equal to the main accumulator pressure under normal operation).

The center element is the suspension control block. The electric valve (bottom left corner) opens the feed pressure to move the control piston in the control block, which opens the center sphere to the rest of the suspension. Note the blue area - the fluid passes through two damping blocks (one for each strut connection) into the middle sphere. When both the struts move in unison, effectively, the middle sphere behaves as a standard sphere with a damper element with a hole twice the area of a single damper element in the suspension block. However, when the fluid moves from one strut to the other, as is the case when the vehicle rolls left-right, it has to pass through both damper elements consecutively. In addition to that, the middle sphere presents a 'spring' that dampens cross flow by absorbing quick changes in pressure between the dampers, additionally slowing the flow of fluid between the corner spheres. In this manner the roll behavior of the suspension is improved.
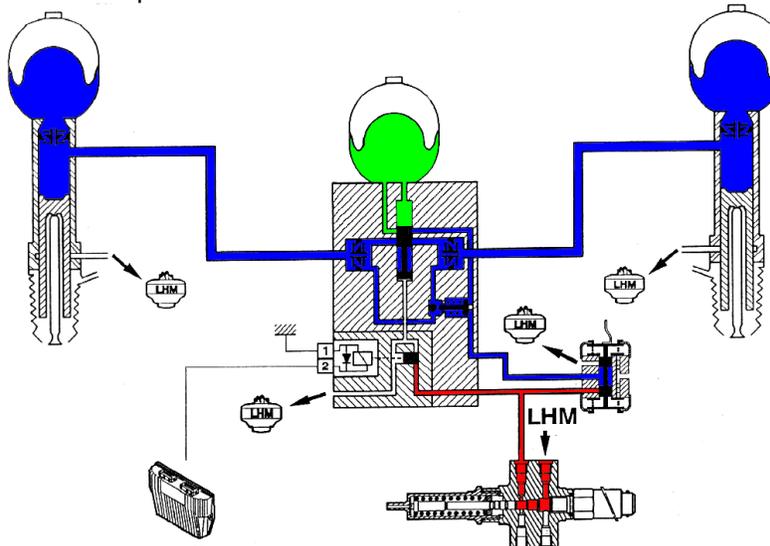
The above picture shows the suspension control block in the hard setting. The electric valve does not let the main feed pressure pass and move the control piston. The pressure inside the middle sphere, which is always higher than that of the return path under normal operating conditions, will move the control piston into a position which closes off the middle sphere completely. The remaining pressure in the middle sphere remains unknown (green area in the picture). The control rules for the electric valve are designed with this in mind, so that the pressure is periodically equalized by enabling the control block to assume the soft setting

for a short period of time. This is done because it is possible that the suspension pressure (blue area) is different at the time the control block goes into hard mode and at the time it returns to soft mode, due to either the dynamics of the suspension (acceleration, braking, movement due to uneven surface), or the vehicle height being set differently.

Cross-flow of fluid from one strut to the other still has to pass through both damper blocks, but it is additionally limited using a simple piston and ball valve, which is now positioned between the damper elements instead of the middle sphere. The ball is positioned in the fluid so that any cross flow moves the ball and thus limits the cross flow. This dampens the cross-flow considerably (see picture below), and thus also body roll.
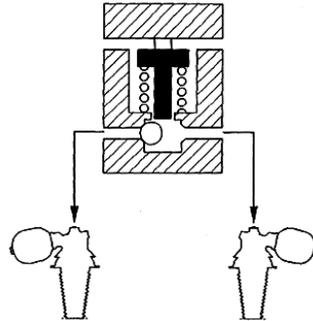
In the picture above, a situation is shown where the vehicle is making a left turn, and tends to roll to the right. This compresses the right strut and expands the left strut, causing a cross flow of fluid, from the compressed strut to the expanded one. This moves the ball in the valve towards outlet to the left strut, closing off further cross-flow. The remaining damping is left to the spheres on the strut.
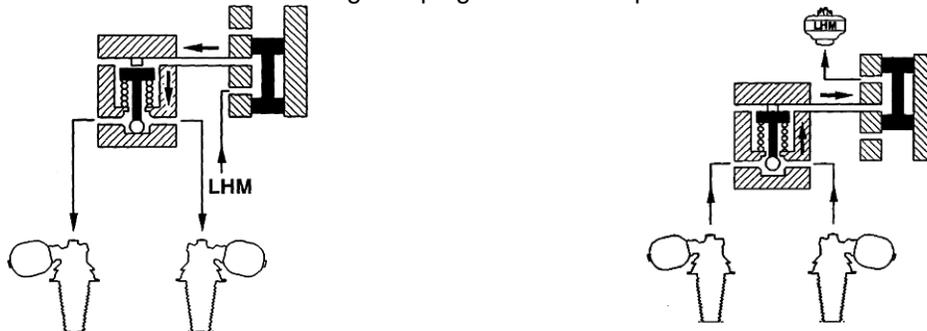
Because it is possible that the vehicle needs to change ground clearance while body roll is present, such as when the vehicle is braking in a curve, the ball valve has an additional piston arrangement in the fluid path from the height corrector. In the pictures above, two situations are shown where height correction is needed. In the left picture, the suspension needs to be raised. This would mean that the pressure on the height regulator side becomes higher than that of the suspension. This situation presses down the piston, which dislodges the ball in the anti-roll valve, to enable the pressure to raise equally in both the left and right strut. If the ball was not dislodged, the pressure would increase only in one strut, thus locking the ball position, and resulting in incorrect suspension operation.

The right picture shows the opposite situation, where the suspension needs to be lowered. In this case, fluid needs to go out of both struts, which dislodges the ball. Because the pressure on the regulator side is now lower than that of the suspension, and both sides of the piston part of the valve effectively present the same surface area, the pressure of the suspension will open the piston towards the return line, and the fluid will escape from the struts lowering the vehicle.

The electronic subsystem

The suspension ECU takes signals from the various sensors and based on two sets of rules (one each for normal and sport suspension), activates the electric valves. Although there are two electric valves that select the suspension setting (one for the front and one for the rear wheels), the ECU operates them as if they were one valve, so in effect, the ECU only has a single output signal.

The ECU uses 7 sensors, which generate a total of 10 'input parameters':

1) Vehicle speed
2) Steering wheel position (2a) and speed (2b)
3) Body movement magnitude (3a) and speed (3b)
4) Gas pedal press (4a) and release (4b) speed
5) Brake pressure sensor
6) Door/boot open sensor
7) Ignition switch on/off

The sensors work as follows:

1) Speed sensor
The sensor is Hall effect based and produces 8 impulses per rotation, or approximately 5 impulses per meter traveled (this depends somewhat on tire size). It is located on the gearbox where the speedometer cable attaches, or in some versions, on the cable itself.

2) Steering wheel angle/speed sensor
The sensor is optoelectronic. It produces a quadrature signal from two optoelectronic sensors, by interrupting the passage of an infra-red beam of light through 28 holes on the sensor corona. The ECU senses signal changes on both optoelecronic sensors to effectively increase the resolution of the sensor (28 impulses per steering wheel revolution) by a factor of four. This produces one edge change every 3.214 degrees of steering wheel rotation.
The signal from the sensor is used in three ways:
a) The straight line position is assumed if the vehicle speed is more than 30km/h and the total accumulation of full quadrature impulses generated was zero within a period of 90 seconds. This is then used as a reference for steering wheel position. Accumulation of full quadrature impulses effectively means that for the accumulation process, the sensor resolution is not multiplied by 4. This is done to avoid sensing small movements which the driver might use to correct miniscule road irregularity or a steering wheel free-play. In order for a pulse to accumulate in this mode, depending on the actual position of the steering sensor, a hole or fill-in has to pass beneath both optoelectronic sensors. In addition, the number of pulses observed in each direction is tallied and the zero position is also corrected using the resulting count. Because the number of steering wheel turns is known (2.94 full left to full right), the sensor can generate a maximum of 84 pulses, 42 in each direction from straight. This process is a lesser rate correction, because up to a 5 pulse difference is possible due to wheel alignment and similar phenomena. A total tally of anything more than 47 pulses in either direction from the current center line, automatically corrects the internal center line reference by the difference between the actual number of pulses observed minus 47.
b) Pulse edges from both optoelectronic sensors within the steering wheel sensor are counted relative to the zero position set in (a) to derive the steering wheel position. The sequence of edge changes from both optoelectronic sensors is used to derive the direction the wheel is turning.
c) The time between the pulse edges is also measured, which is used to derive the steering wheel speed.

3) The body movement sensor
This is similar to the steering wheel sensor. It consists of two optoelectronic sensors with two infrared beams being either blocked or alowed to pass by a disc which has 45 notches on it's corona, producing 45 full quadrature pulse cycles per revolution. The ECU again uses the signal edges from the two optoelectronc sensors to quadruple the resolution of the sensor. Excessively long intervals between impulses are taken as suspension travel as a result of a different height setting being chosen, and are not taken into account. Similar to the steering wheel sensor, the body movement sensor is used to derive the body movement amplitude, as well as speed of movement.
Due to the way the sensor is set up, it is capable of detecting squat/dive and to an extent, roll. The sensor is connected to the front anti-roll bar to the right of the height corrector linkage. Since the sensor is mounted off center on the anti-roll bar, it's sensitivity to roll is about three times less than it's sensitivity to squat/dive. Only a small amount of the full circumference of the corona is used due to this linkage arrangement, unfortunately, the documentation is not exactly clear as to what number of impulses from the sensor corresponds to what amount of body movement. The picture below shows how the sensor looks. Note the

'handle' on the back side (left side of the picture), ending in a small ball joint. This is connected to the linkage using a small plastic rod with ball sockets on each end, the same as used in the height corrector linkage. The sensor is made by Valleo and is located between the right wheel and the height corrector, a few inches from the roll-bar.
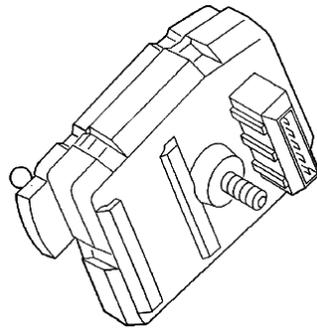
4) The gas pedal position
This sensor is a 4.7kohm potentiometer linked to the gas pedal by a sprung lever. The wiper of the potentiometer has an integrated 2kohm series resistance. The sensor is located below the dashboard right next to the gas pedal mechanism, and the little 'lever' on it is mover by the gas pedal moving (see pictures below). The lever is sprung by a spring inside the sensor.
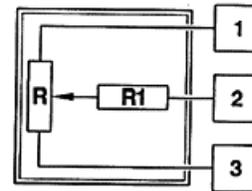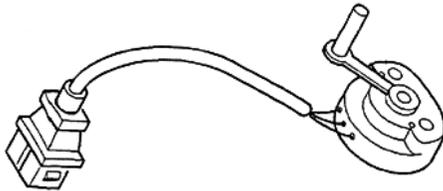
The entire travel of the potentiometer is divided into 256 steps by the ECU. In effect, the sensor is supplied from a 5V reference source within the ECU, which is also the full scale reference for an 8-bit A/D converter. The sensor then divides the 5V reference voltage, connected between pins 1 and 3, and the input of the A/D converter within the ECU is connected between pins 2 and 3. Due to the gas pedal initial position and maximum travel variations the full travel of the pedal will result in 160 to 220 steps out of 256 being usable. However, the signal from the sensor is only taken as a relative value, so the actual number of usable steps is not an issue.

5) The brake pressure sensor
This is a simple pressure activated switch. The activation pressure is 30 bars. The sensor is located on a hydraulic conduit connector block, right next to the ABS block. The two are located at the bottom of the left front wing, in front of the wheel, and under the battery. The sensor looks as shown below:
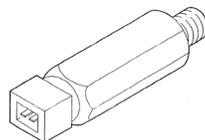
6*) The door/boot open switches*
These switches are located on the door frame and in the boot latch. There are actually two inputs for switches on the ECU. The door switches are all wired together and connected to one input, and also routed to the interior light dimmer/timer. The boot switch is connected to the other input and also routed to the boot light and the boot lid opened detection input for the status display on the dashboard. The door open and bonnet open signals for the status display are generated by a separate set of switches completely independent of the ones described above!

7) Ignition switch
This is used as a power on sensor and will generate an internal reset and self-diagnostic of the ECU. Turning the ignition on and off also generates internal events that guarantee proper pressure equalisation between the central and corner spheres.

Operation:

The ECU is a microcontroller-based unit, that implements suspension control rules. In general, the ECU uses signals from sensors 2, 3 and 4, and to an extent 5, 6 and 7 in relation to vehicle speed (sensor 1) to form various threshold tables. When any of the given sensor inputs cross a threshold value in a table, the suspension is put into hard mode (in other words, there is an implied logical 'OR' function for the sensor inputs). The threshold cross for each table is also subject to a timeout value - the signal has to remain under the threshold value for a certain amount of time before a given sensor input will not generate a 'hard suspension' signal.

In addition, there are four rules which supercede the operation as stated above:

1) The ECU puts the suspension into SOFT mode when the ignition is turned on or off. This setting supercedes all other rules until a 30 second time out runs out or the vehicle speed exceeds 24 km/h, whichever comes first.

2) If the ECU determines that there is a problem within itself or any of the sensors or the electric valves, the suspension will go into hard mode at first occasion and stay in hard mode until the ignition is turned off, or the doors are opened while the vehicle speed is lower than 24 km/h. The ECU runs a self-diagnostic when the ignition is turned on. Some sensors, however, cannot be tested at power-up. The ECU will generate faults if the sensor inputs do not correlate - for instance, no body movement but speed greater than 24 km/h, etc.

3) When the suspension stays in hard mode for more than two minutes, the ECU generates a momentary reset of the suspension to soft mode, to assure equalization of the pressures between the corner and the center spheres. If the hard mode signal persists, the suspension will return to hard mode within 50 ms, after which the 2 minute timeout will be restarted. The timeout is reset every time the suspension returns to soft mode.

4) Under 24km/h opening the doors or boot overrides any other rules.

Rules that use input from other sensors are given below:

The steering wheel sensor is used to derive two inputs: steering wheel speed and steering wheel angle. Both values are treated separately. The purpose of this is to calculate the lateral acceleration of the vehicle (vehicle speed, steering angle) and the potential change in lateral acceleration (vehicle speed, steering wheel speed). I suspect it was done this way to save a large amount of memory which would be required for a three-parameter lookup (vehicle speed, steering wheel angle, steering wheel speed). The steering wheel sensor rules actually give a measure of potential body roll. Body roll is significantly reduced in hard mode, therefore the rules have to be set up so that the body roll is minimized when there is potential for it, but that the suspension stays soft to absorb bumps when there is no body roll caused by the vehicle changing direction.

The table below gives a threshold of steering wheel angle. If the steering wheel angle is more than the threshold for a given vehicle speed, the suspension will go into hard mode. It will go into soft mode again if the threshold angle in the table is not exceeded again within a period of 1.5 seconds:

Vehicle speed (km/h)	Steering wheel angle (deg.)	
	NORMAL	SPORT
<34	N/A	N/A
34-39	174	119
40-49	100	67
50-59	84	56
60-68	68	45
69-78	55	37
79-89	42	28
90-99	33	22
100-119	26	17
120-139	23	15
140-158	20	13
159-179	13	9
>179	10	7

The table below gives a threshold of steering wheel speed. If the steering wheel speed is higher than the threshold for a given vehicle speed, the suspension will go into hard mode. It will go into soft mode again if the threshold speed in the table is not exceeded again within a period of 1.5 seconds.

Vehicle speed (km/h)	Steering wheel speed (deg/s)	
	NORMAL	SPORT
<24	N/A	N/A
24-29	535	357
30-39	401	267
40-49	246	164
50-59	178	119
60-68	110	73
69-78	82	55
79-89	62	41
90-99	53	35
100-119	42	28
120-139	30	20
140-158	22	15
>158	20	13

The body movement amplitude and speed is derived from the output of the body movement sensor. The amplitude and speed are, however, used in a different manner.
The body movement speed is used as the parameter for the activation of two types of corrections:
1) 'flat tire' correction. If the body movement speed exceeds 300mm/sec the suspension goes into hard mode, and all the hard mode thresholds are limited to 60mm. The timeout of the correction is 0.4s.
2) Excessive body movement correction. If the body movement exceeds 60 mm more than three times within three seconds, the suspension will be put into hard mode, and all the hard mode thresholds are limited to 60 mm. the timeout for this correction is also 0.4s.
The corrections stay enforced until one or more of the following conditions are satisfied:
1) body movement amplitude remains under the 'hard' threshold during the correction timeout.
2) The suspension selector is set to 'Sport'.
3) The vehicle speed becomes higher than 159km/h.
4) The steering wheel angle is higher than a threshold value dependent on vehicle speed as specified in the table below.
Once either of the above conditions is satisfied, the suspension will go to normal operation, with thresholds set as in the table below. Crossing the thresholds will put the suspension into hard mode, and keep it there for 0.8 seconds unless the thresholds are crossed again, which resets the timeout, so it starts anew, and keeps the suspension in hard mode.

Vehicle speed (km/h)	Dive (mm)	Squat (mm)	Steering wheel position (deg)
<10	N/A	N/A	N/A
10-33	84	60	N/A
34-39	84	60	87
40-49	54	48	50
50-59	54	48	42
60-68	54	48	34
69-78	54	48	27.5
79-89	54	48	21
90-99	48	48	16.5
100-109	48	48	13
110-119	48	42	13
120-129	48	42	11.5
130-139	42	42	11.5
140-149	42	42	10
150-158	42	36	10
159-179	42	36	6.5
>179	36	36	5

Note that the rules governing suspension setting vs. body movement are the same for both normal or sport suspension settings.

Gas pedal speed is taken in relation to vehicle speed. This is done to anticipate the vehicle dynamics as a result of acceleration or engine braking. The rules for this sensor represent a reaction to potential vehicle squat (on acceleration) or dive (on engine braking). Both are significantly reduced when the suspension is in HARD mode.
The number of A/D converter 'steps' traveled within 25ms is taken as the measure of gas pedal position rate of change (i.e. gas pedal speed). Separate rules are used for pedal pressing and releasing, as are given in the following table:

Vehicle speed (km/h)	Gas pedal press speed (steps/25ms)	
	NORMAL	SPORT
0-14	2	1.3
15-49	3	2
50-99	4	2.6
100-134	5	3.3
135-199	6	4
>199	7	4.6
	Gas pedal release speed (steps/25ms)	
0-19	10	6.6
20-78	5	3.3
79-168	6	4
>168	7	4.6

The table again gives thresholds, which, once crossed, cause the suspension to go into hard mode. The suspension will go back to soft mode if the threshold is not crossed within 1.6 seconds of the suspension going into hard mode.

The brake pressure sensor detects pressure in the front brake hydraulic circuit. Since this is a fixed threshold sensor, the suspension setting rule is simple. If the vehicle speed is higher than 24km/h AND the pressure sensor is active, indicating that the pressure in the brake circuit is 30 bar or more, the suspension will go into hard mode. The suspension will remain in hard mode as long as the rule above is satisfied. This is done to prevent excessive dive when brakes are applied.

The door and boot open sensors will override the hard setting of the suspension as long as the vehicle speed is below 24 km/h. The suspension will consequently go into soft mode whenever any door or the boot is opened, and will remain in soft mode for 30 seconds after all the doors are closed if the vehicle speed remains below 24 km/h. As long as the vehicle maintains a speed of at least 24km/h, normal rules apply, and will continue to apply even if the doors remain open. It is important to note that the suspension will go into soft mode even with the ignition switch turned off. Should the doors remain open with the ignition switch in the off position, the suspension soft setting will be subjected to a 10 minute timeout to avoid draining the battery, as the soft setting requires the electric valves to be energized.

The ignition switch change of state provokes a soft setting starting a 30 second timeout, which can be terminated by the vehicle speed reaching 24km/h. When the ignition is turned on, the ECU also goes through a self-test sequence, which lasts 3 seconds.

The suspension mode select switch chooses one of two sets of rules for suspension behavior. The rules are slightly more strict for the sport setting, the suspension will go into hard mode much more readily, because most of the thresholds are reduced.

The suspension status light has a double function:
1) When the ignition switch is turned on, and the suspension mode is set to normal, the light will go on during the three-second duration of the ECU self test, if the test is successful. If the test is unsuccessful, i.e.

there is something wrong with the ECU or the sensors at self-test time, there will be one or more flashes of the light during the 3 second self-test interval.

2) When the suspension is set to sport, the status light will remain lit to indicate the sport setting has been chosen.

The status light actually lights up or extinguishes itself only when the suspension rules have been changed in response to the mode select switch. This takes a short while because the internal timeouts are reset and some of the sensors are re-calibrated. Because of this the light changing state is slightly delayed from the mode switch changing state.

Differences between Hydractive I and II

Hydractive I has roughly the same functionality for the hydraulic elements, with one exception: there is no roll limit ball/piston valve for the soft setting. Because of this hydractive I limits roll by using significantly more damped corner spheres, to increase the potential cross-flow of fluid between the struts in order for the dual damper arrangement of the center sphere to damp them. This however, requires a greater damping setting for both modes, or a sacrifice in handling quality, a situation which is difficult to find a good compromise for. The actual hydraulic elements, although similar in function, are quite different for hydractive I and II, just about the only thing similar are the spheres. The suspension control elements do not have integrated electric valves. Instead, one electric valve is located separately, and the control pistons within the control units are hydraulically controlled, through hydraulic conduits which provide the connection to the electric valve. The integration of the electric valve and the control element body in hydractive II reduces the number of hydraulic conduits.

The greatest difference in the way hydractive I and II are set up is the ECU. Although the sensors are almost completely the same (except for the speed sensor which is a tachogenerator in hydractive I and a hall switch in hydractive II), the logic of operation of the ECU is different. Hydractive I only has one single set of rules, which is applied only when the suspension is set to 'automatic'. When the suspension mode is set to 'sport', the suspension is set to hard, and stays in that setting until the suspension mode is returned to 'automatic', except during a brief period of the ECU self-test, which is similar in operation to Hydractive II.

Hydractive II uses both the soft and hard setting for both mode settings, which have been changed from 'automatic' and 'sport' in hydractive I to 'normal' and 'sport' in hydractive II. With hydractive II, each suspension mode setting has a separate set of rules.

Possible improvements and projects

A replacement ECU for hydractive I could be made that would enable the suspension to behave similar to hydractive II, the only difference would be the absence of hydraulic roll limiting in soft mode.

Also, a replacement ECU could be made that could be used for both Hydractive I and II setups, which would have several settings, instead of just two. It would even be possible to make the mode continuously variable between a constant hard setting, and a setting which mostly stays soft, having very relaxed rules that generate a transition to hard mode.

The hydractive II setup could also be modified to control the front and rear electric valves separately. In particular, a setting with more stringent rules for the rear suspension could be very beneficial in situations where a relatively lightly loaded car is used to tow a trailer. In this situation, having only the rear suspension more readily go into hard mode, or even stay in hard mode, could be a good idea. However, this is only possible for hydractive II – hydractive I is hydraulically connected to operate both suspension control blocks simultaneously.

Another possibility would be an 'acceleration based' rule for steering wheel speed/angle and vehicle speed - i.e. a true three-parameter lookup table. Memory technology has considerably advanced since either Hydractive I or II ECUs were designed, the memory overhead for a three parameter lookup would be insignificant in terms of today's available memory capacity.

A replacement ECU would of course have a 'download' feature, for instance via a serial port. This could be used to customize suspension behavior, possibly even by the user.

Improving suspension comfort

1) Adjustments to the hydraulic elements
Although so called 'comfort spheres' are available, this is not the real answer to the constant complaints of drivers used to older Citroens that the XM's suspension is 'not as comfortable'.
Comfort spheres are only mounted onto the struts. This reduces the damping of the suspension in both modes, because 'comfort spheres' usually have the damping elements with a larger bore, and they are always connected to the suspension, regardless of suspension setting. Unfortunately, this also compromises handling, because it affects roll and dive/squat behavior.
In order to adjust the suspension differently, the 'spring constant' of the spheres has to be adjusted lower together with the damping. In order to do this, the pressure in the spheres has to be increased, but this may limit suspension travel in hard mode, unless the sphere volume is also enlarged. It will also result in greater changes in suspension behavior for different load situations. All these requirements significantly reduce the options for usable spheres.
A better option would be to partially disassemble the suspension control element and bore out the damper elements within it. Also, a higher pressure sphere can be fitted as the center sphere (for instance, an accumulator sphere). In case of the middle sphere the volume is not critical as there are three spheres working when the suspension is in soft mode, which gives a sufficient headroom for fluid displacement. This setup will not affect hard mode roll performance, but will affect soft mode roll. It will also significantly reduce damping and resonance frequency in soft mode.
This alternative setup will not significantly affect handling because that is mostly determined by the hard suspension setting, and this has not been changed.

2) Adjustments to the electronic elements
Changes to the ECU rules without changing any of the hydraulic elements could probably increase the comfort of the suspension as well, however, this may compromise handling, because the basic suspension behavior is dictated by the hydraulic elements. The suspension could be 'tuned' to run in soft mode more often, by relaxing the rules that put it into hard mode.
Changes to the hydraulic elements should ideally be accompanied by changes to the ECU rules. In any case, any changes to the existing ECU are only possible by reprogramming it. The available documentation leaves the question of reprogramming open – there is no data about this. A replacement ECU would, of course, easily be made to be reprogrammed as needed.