NIVOMAT

The Automatic Level Control System with Spring Function and Damping Function

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Lecture given as part of the course
"Springing and damping systems for road and rail vehicles"
at the Technical Academy of Esslingen
on 11 Oct. 2000

TABLE OF CONTENTS

NIVOMAT – THE AUTOMATIC LEVEL CONTROL SYSTEM WITH SPRING FUNCTION AND DAMPING FUNCTION

1. General Description

The Mannesmann-Sachs Nivomat is a compact device for vehicle level control, containing all necessary system elements (supporting element, pump, accumulator, reservoir, regulator, etc.) in one housing. The Nivomat is installed instead of a conventional shock absorber, spring shock absorber or spring strut and automatically establishes the optimum vehicle level under all load conditions. In general, the Nivomat also takes over the spring and damping function. The installation of the Nivomat is usually carried out at the rear axle of a vehicle, thus level control with the Nivomat is also carried out there.

The specific characteristic of the Nivomat level control system lies in the fact that the energy necessary for adjusting the optimum height level is generated from the relative movements between the axle and the vehicle body arising from road irregularities while driving. This means that - in contrast to other systems - the Nivomat operates without any pollution since it does not need any external energy supply.

2. Principle of Operation

The principle of operation of the level control element is illustrated by **Fig. 1**. The figure shows diagrammatically the major function elements of the Nivomat in two different operating states. The following elements are shown: low-pressure reservoir, high-pressure accumulator, pump with inlet and outlet valves, height regulator and supporting element. The working media oil and gas are identified. Height regulator, supporting element and the push rod of the pump are rigidly connected with the piston rod.

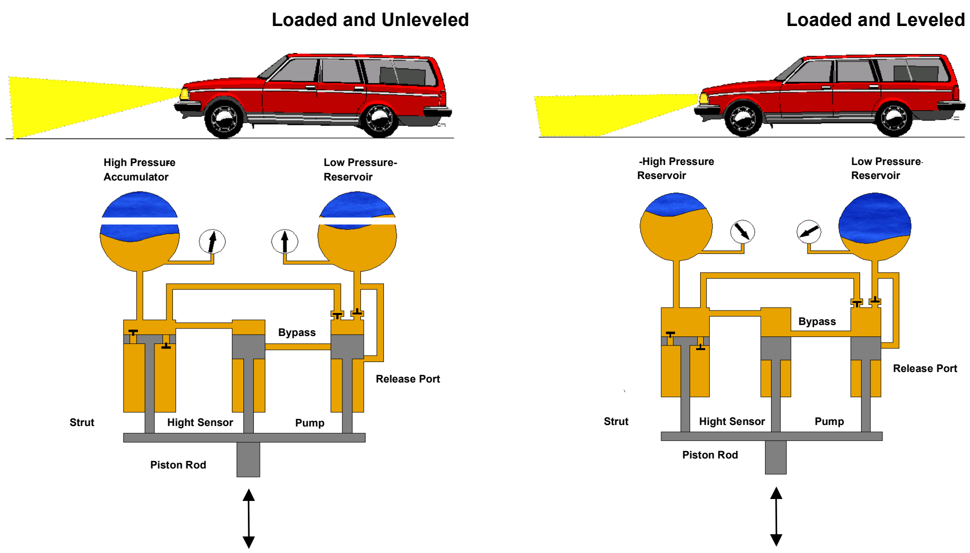


Fig. 1: Nivomat – Schematic function

Fig. 1 shows the state "loaded and uncontrolled", which comes about, for example, when the stationary vehicle is loaded. When the vehicle moves off, the relative movements between the axle and the body result in the oil being pumped from the low-pressure reservoir against the gas cushion in the high-pressure accumulator. During the outwards movement of the piston rod, the oil is sucked into the pump through the inlet valve; during the inwards movement, the oil is pressed into the high-pressure accumulator through the outlet valve. The pressure in the low-pressure accumulator decreases continuously, and the pressure in the high-pressure accumulator increases continuously.

Also shown is the operating state "loaded and controlled", which comes about when the Nivomat has adjusted the optimum vehicle level position. The increased pressure in the high-pressure accumulator, which acts on the supporting element at the same time, has increased the piston rod extension force and has lifted the vehicle body. Further pumping does generally not lead to a further pressure increase because the height regulator opens a bypass between the working chamber and the pump chamber, which prevents further oil supply from the low-pressure reservoir.

3. Structural Design

The major design elements of a Nivomat are illustrated in **Fig. 2**. The piston rod is hollow and guides a so-called control sleeve which, along with the fixed pump rod and the inlet and outlet valves, makes up the pump. The damping piston with its valve discs is attached at the inner end of the piston rod and moves in a cylinder tube. Gas and oil are separated on the high-pressure side by a diaphragm.

4. Spectrum of Capabilities

4.1 Spring Function

The Nivomat is generally used as a partially loaded element on the rear axle of the vehicle. In this case, the greater part of the dead weight of the vehicle (rear) is supported by a mechanical spring (spiral or leaf spring), which is installed parallel to the Nivomat. Here, the Nivomat's function is to support the major part of the payload. When deploying the fully loaded Nivomat system, the Nivomat supports and cushions the entire vehicle weight, including the payload.

When deploying a partially loaded Nivomat system, three spring elements are of importance. These elements are the mechanical supporting spring, the gas spring (due to the enclosed gas volume in the high-pressure accumulator of the Nivomat) and a pressure bump stop. The mechanical spring is designed to be weaker than a conventional shock absorber application as the Nivomat already provides part of the spring force. The pressure bump stop becomes effective with increasing compression and limits the compression travel.

NIVOMAT - Main elements

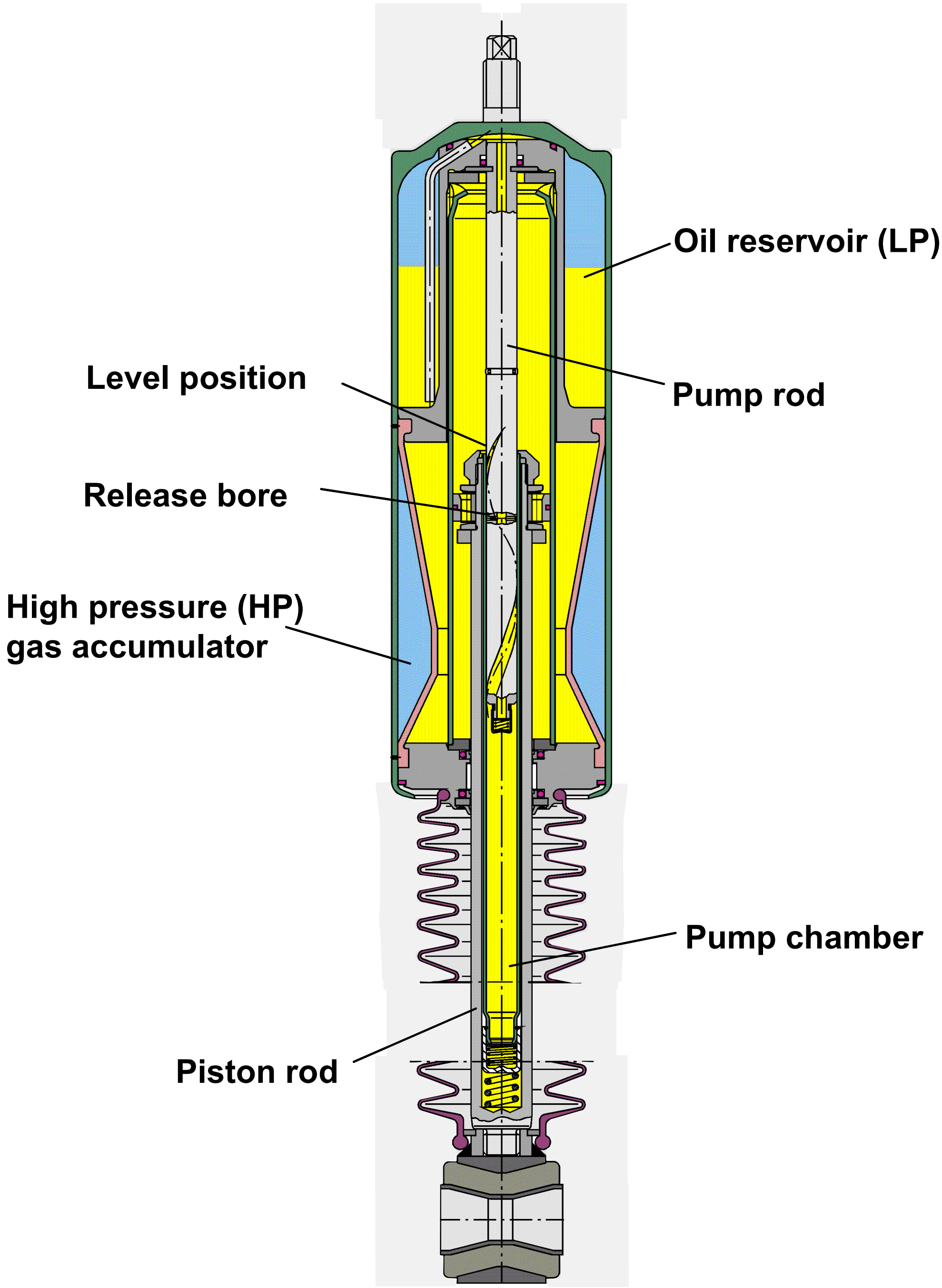


Fig. 2: Nivomat – structural design

The spring characteristics of the Nivomat result from the overlapping of the three spring elements, as illustrated in **Fig. 3** by a comparison with a conventional chassis suspension. The linear characteristic of the mechanical spring passes through point A* in case of the dead vehicle weight and through point B* in case of maximum payload and static compression.

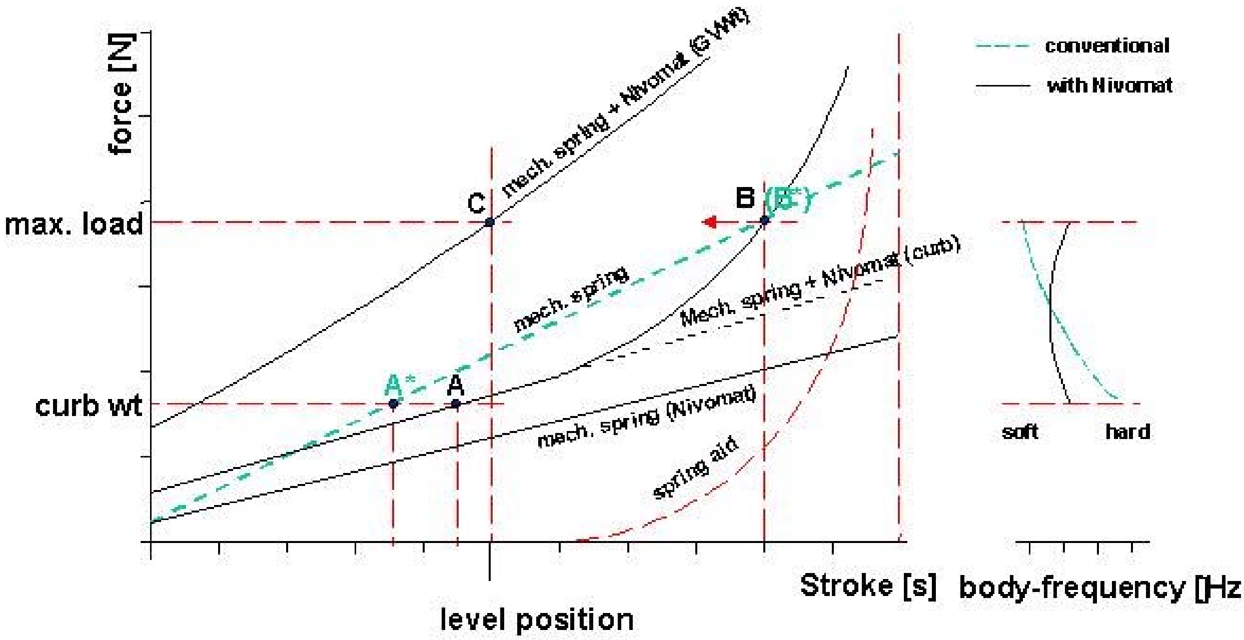


Fig. 3: Nivomat spring characteristics

In case of the Nivomat application, a dynamic level position is determined together with the vehicle manufacturer. The level of the unloaded, stationary vehicle when the Nivomat is used (point A) can be set at the same point or lower as compared to the conventional suspension springing. However, the static compression in the case of maximum payload (point B) should correspond exactly to the conventional deflection under full load (point B) so that the vehicle has the same ground clearance in this case. While being driven, the vehicle will then be lifted to the predefined "dynamic" level (point C). This requires a driven distance of 500 m to 1500 m, depending on the road conditions.

The characteristics diagram clearly shows the increase of the spring rates with increasing payload, caused by the increasing compression of the gas cushion in the Nivomat. For reasons of comfort and security, the vehicle manufacturers' objective is to reach an oscillation frequency of the vehicle body as constant as possible over the entire payload range. With conventionally suspended axles the oscillation frequency generally varies clearly between the dead weight and the full payload (e.g. 1.47 dead / 1.01 full), whereas it is almost constant with a

Nivomat system (e.g. 1.38 empty / 1.48 full) (**Fig. 3**). Thus, Nivomat applications are usually less hard in the empty state and less soft in the fully loaded state.

A further advantage of the Nivomat-suspended axle results from the possibility to decrease the overall spring travel while still obtaining the same or even a larger dynamic spring travel (**Fig. 4**). This is often used especially in lowered vehicles.

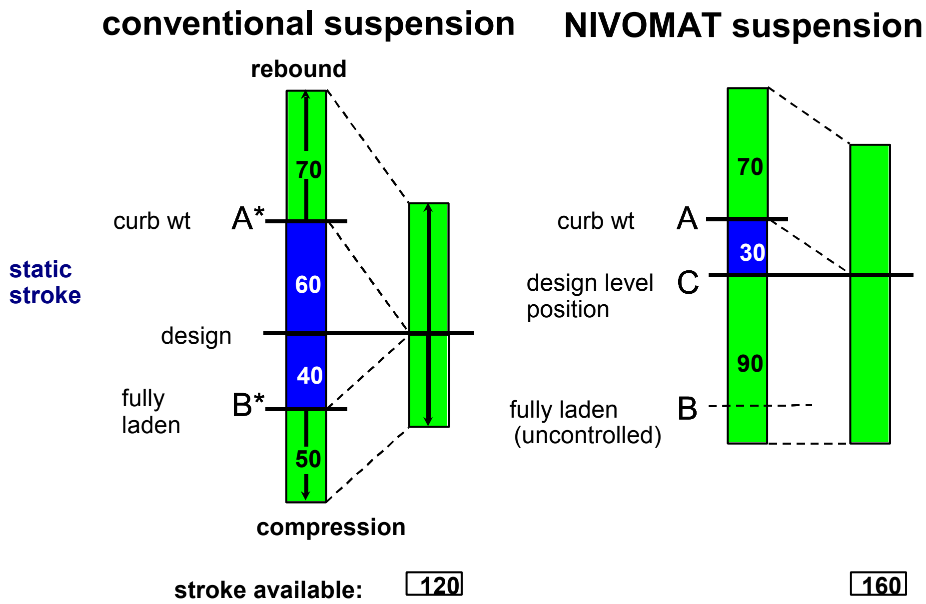


Fig. 4: Nivomat stroke in comparison with conventional damper

4.2 Level Control

The level control with the Nivomat is usually carried out at the rear axle and can only be performed while driving because the internal pump is operated by the relative movements between the body and the axle caused by road irregularities. However, the Nivomat does not drop immediately as soon as the vehicle stops but, due to its internal tightness, it can maintain the level reached for a longer period.

The Nivomat pump is operated by the piston rod. When the piston rod is moved out (pull), the pump chamber is expanded. Oil is sucked from the low-pressure reservoir into the pump chamber through the suction tube, the hollow pump rod and the open inlet valve. When the piston rod is moved in (push), the pump chamber is made smaller, the inlet valve closes and the outlet valve opens. Oil is pressed into the working chamber between the exterior side of the control sleeve and the interior side of the piston rod. At the same time, oil is displaced into the high-pressure accumulator through the open side of the cylinder tube. The high-pressure gas cushion is increasingly compressed during pumping.

When approaching the intended vehicle level, a spiral groove, located on the pump rod and until then covered by the control sleeve, is opened. The opened groove forms a bypass between the pump chamber and the high-pressure accumulator. Thus, no more oil is sucked out of the low-pressure reservoir; oil is only moved between the pump chamber and the working chamber.

When the vehicle is being unloaded while stationary, the piston rod first moves out further since the balance between the Nivomat extension force and the load on the Nivomat is disturbed. This further extension of the piston rod causes a relief bore on the pump rod to be opened. At the level position, this relief bore is covered by the control sleeve. It allows an oil flow from the high-pressure accumulator into the low-pressure reservoir, which results in a corresponding pressure reduction.
When driving on bumpy roads the Nivomat is excited more than normal. In this case, the Nivomat adjusts to a higher level (15 - 20 mm). This results in the vehicle reaching a greater ground clearance, depending on the ratio of movement between the Nivomat and the wheel.

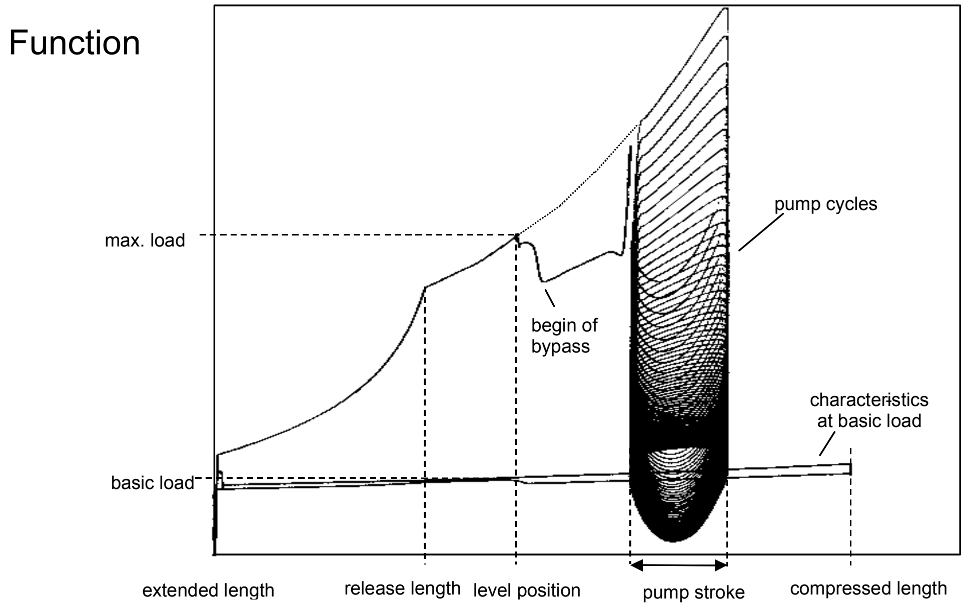


Fig. 5: Nivomat pump diagram

Fig. 5 shows a typical Nivomat pump diagram as recorded during a functional test. In the lower section, the basic characteristic of the device at a base pressure (20 - 50 bar) is recorded. Then the device is pumped up to the supported load (90 - 130 bar) in the area of the pump (bypass closed) by constant strokes. During this, the increase of the spring rate can clearly be seen. Then the relief function is activated by the extension of the piston rod, and the pressure in the Nivomat drops to base pressure. In case of dynamic pressure application, pressures of up to 350 bar may occur in the device; sealing and guidance on the piston side are therefore of special significance.

4.3 Damping

The damping of the Nivomat is characterized by a speed-dependent basic damping and a load-sensitive additional damping.

The basic damping results from a single-tube design, as with conventional vibration dampers. When the piston moves in the damping liquid, the liquid flows through the piston valves and the resulting energy of flow is converted to heat. The damping curves (**Fig. 6**) can be influenced by the design of the piston and the valves. Factors influencing damping include especially the shape and size of the constant passage (CP) and the number, size and thickness of the valve discs (spring leaves).

Damping

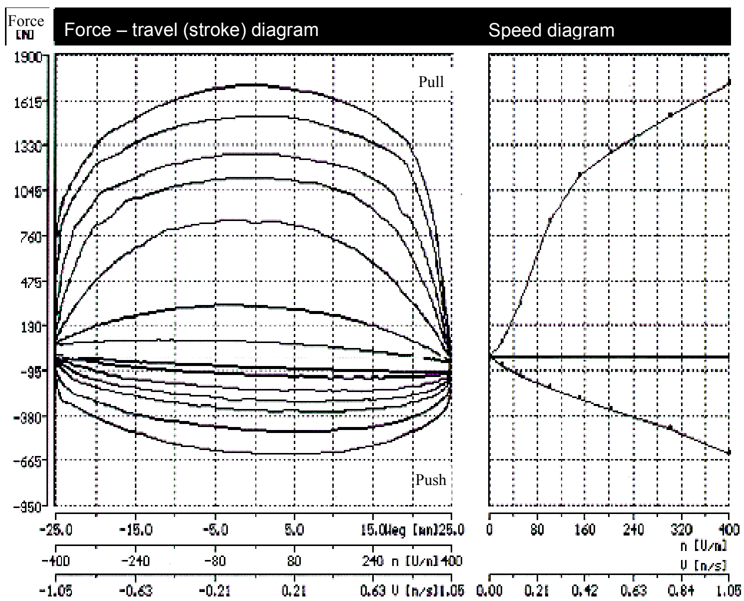
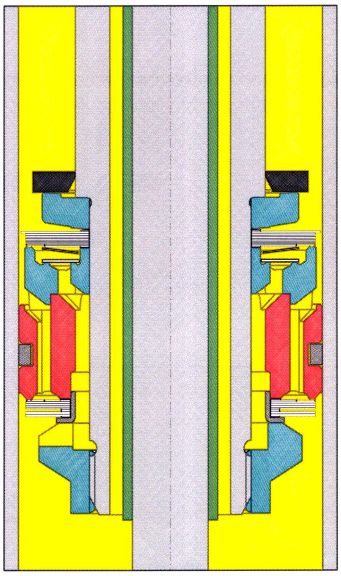


Fig. 6: Nivomat damping curves

A newly-developed piston system (comfort piston) leads to manifold possibilities of designing the damping curves individually. **Fig. 7** shows some of the curves that can be realized with this system. The independent determination of the CP values in the tension and compression strokes and the development of degressive curves should be emphasized.



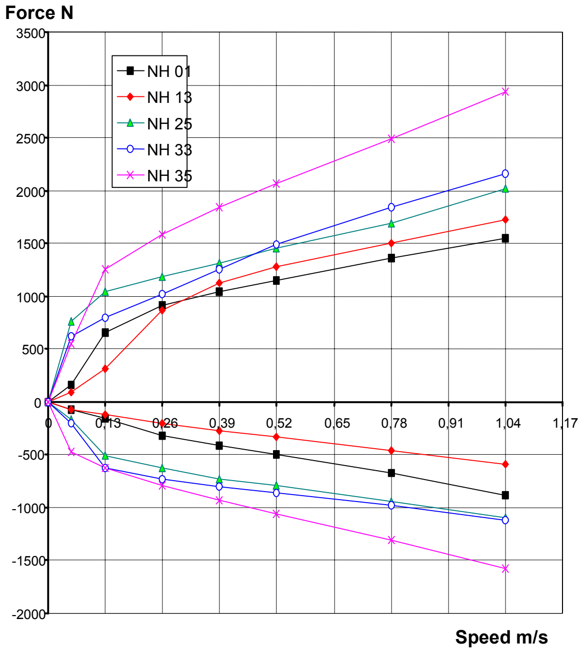


Fig. 7: Design of characteristic curves with "comfort piston"

The load-sensitive additional damping results from the pumping work by the Nivomat. It always acts in pull direction and increases with increasing load supported. **Fig. 8** illustrates the influence of the load-sensitive damping.

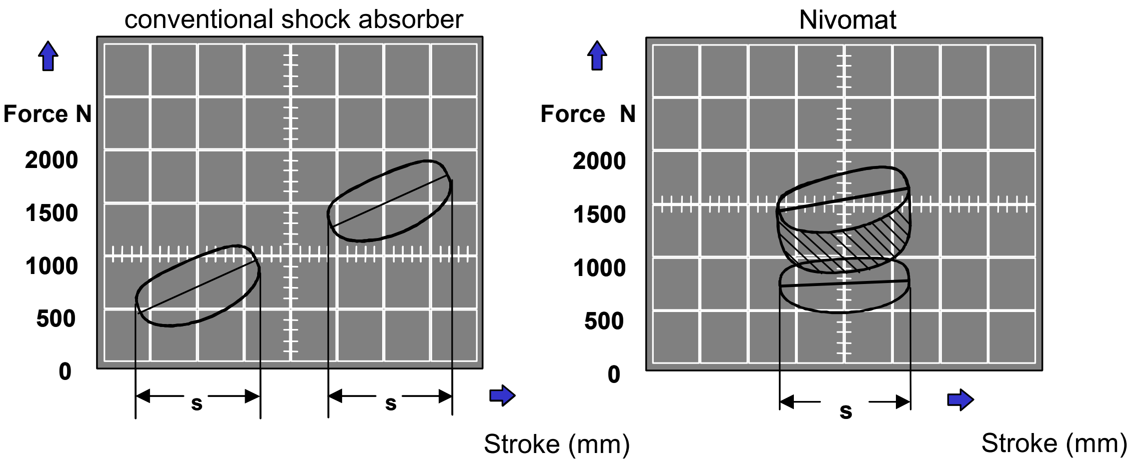


Fig. 8: Load-sensitive damping

5. Dimensioning

The use of the Nivomat control system in a vehicle requires some marginal design conditions.

Firstly, the Nivomat requires more installation space than a normal shock absorber. The standard outer tube diameters are 54 mm for separating piston devices and 60, 63, 68 and 72 mm for diaphgram devices today. However, the outer tube can be adapted - within certain limits - to the specific conditions in the vehicle's wheelhouse. This, however, generally also causes higher costs.

Secondly, the movement ratio of the Nivomat and the wheel must be considered. If the ratio is small, the pump in the Nivomat is excited less, and vice versa. This is of significance especially for dimensioning of the pump (pump rod diameter 10 or 8 mm). High ratios and thus small pump rod diameters can advantage passenger comfort.

The attachment points on the vehicle must be dimensioned adequately for the Nivomat application. The attachments have to transmit greater forces than the damper since the damping force and bump force are supplemented by the Nivomat spring force component.

The mechanical spring must be dimensioned weaker than a damper solution, as indicated above, since the Nivomat takes over a portion of the spring force. When combined with the Nivomat, the bump stop must be dimensioned separately. Since the mechanical spring, the Nivomat and the pressure bump stop comprise one system, individual elements must not be modified independently from each other during vehicle design.
If a level control system with the Nivomat is planned for a new vehicle, we would recommend participation of the SACHS Design Department in the design process as early as possible for the above reasons.

6. Applications

The Nivomat can be implemented as a conventional shock absorber, spring shock absorber or spring strut design (**Fig. 9**). In principle, the Nivomat can be installed with the piston rod pointing upwards or downwards. The attachments to the vehicle are generally customer-specific and can be a pin-type or eye-type joint.

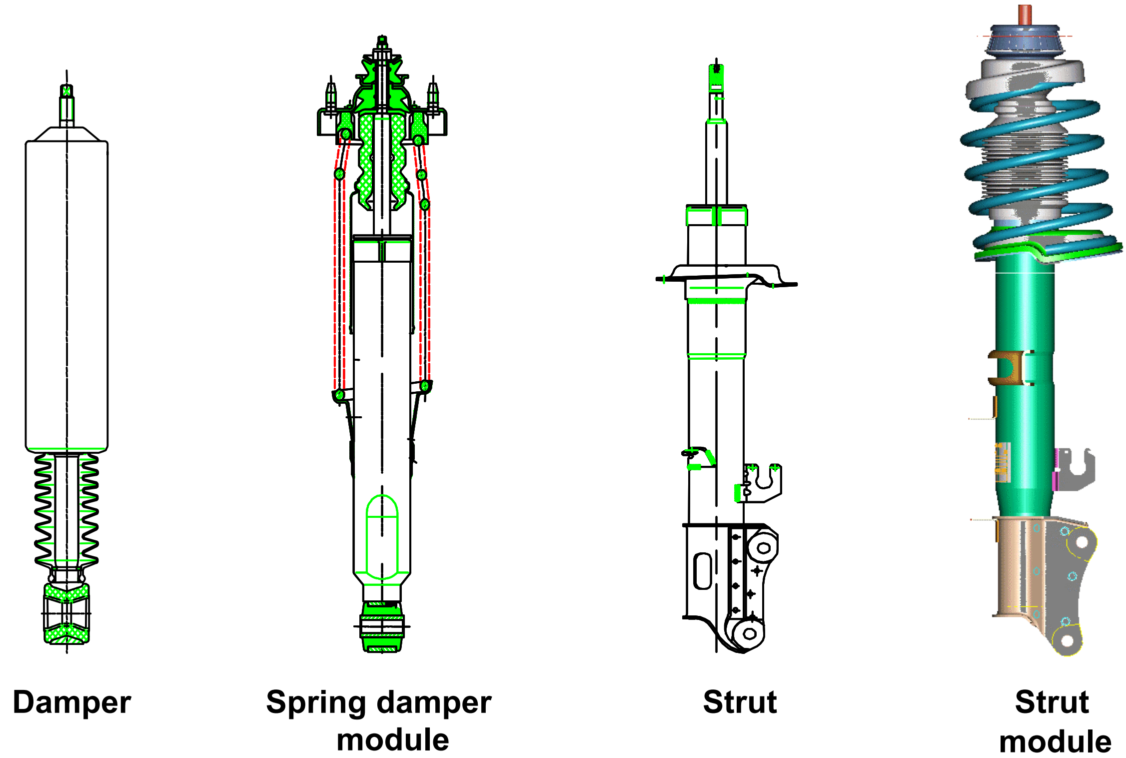


Fig. 9: Nivomat design versions

Especially suited for level control systems are vehicles carrying heavy loads, passenger cars with high comfort and safety requirements, lowered vehicles and vehicles intended for trailer operation.

Today, typical Nivomat vehicles are estate cars, MPVs, SUVs, saloons and various special vehicles (ADAC, ambulance cars, etc.). Applications for lightweight vehicles and pick-ups are increasingly designed now. A Nivomat for motorcycles also exists.

The table in **Fig. 10** shows some of the recent applications currently in series production.

Customer	Type	Car version
Daimler Chrysler	Voyager	Van
Fiat / Lancia	Kappa	Wagon
Fiat / Lancia	Lybra	Wagon
Fiat / Alfa	156 PW	Wagon (Std.+Sport)
Ford	Mondeo	Wagon (Std.+Sport)
Ford	Galaxy	Van
Ford	Focus (in 2000)	Wagopn
GM	Suburban/Tahoe	SUV
Jaguar	XJ6, XJ12	Sedan

Customer	Type	Car version
Mitsubishi	Galant 2WD/4WD	Sedan/Wag.(+Sport)
Opel	Vectra	Wagon
Saab	9-5	Sedan (Std.+Sport)
Saab	9-5	Wagon (Std.+Sport
Volvo	S80	Sedan (Std.+Sport)
Volvo	S70 FWD/AWD	Wagon (Std.+Sport)
Volvo	S60 (in 2000)	Sedan (Std.+Sport)
Volvo/NedCar	S40	Sedan (Std.+Sport)
Volvo/NedCar	V40	Wagon (Std.+Sport)

Fig. 10: Most important NIVOMAT applications (OE/OES)

7. Production

At present, Nivomats are produced by Mannesmann Sachs AG in two production plants. The plant in Munich (Germany) produces ca. 300,000 units annually for the European and Asian markets. The plant in Florence (Kentucky, USA) produces around 750,000 units annually for the American market. In total, about 95 different types are currently produced, which are delivered to 14 different customers. Both plants are certified according to QS 9000 / VDA 6.1 / KBA.

Due to the Nivomat's principle of operation the requirements regarding the cleanliness of the assembly processes and the individual parts used must be very high. The usual general conditions for shock absorber production are not adequate here. All purchased and in-house produced parts must be subjected to special cleaning processes. After the final assembly, every Nivomat is subjected to a 100% function and damping test.

8. System Comparison

To allow the comparison of the quality of different level control systems, a catalogue of characteristics was laid down by the Chassis Development Department of Mannesmann Sachs AG. **Fig. 11** shows the characteristics with an evaluation for the air spring, hydro-pneumatic suspension (suspension cylinder) and Nivomat systems. The level control systems were each assumed as being of the partially loaded, single type with all accessory components, designed for single-axle control (acting on the rear axle). **Fig. 12** shows the result of the evaluation in a graphic way.

SACHS

No.	Characteristic	Nivomat		Pneumatic suspension		Hydropneumatic suspension	
	Comparative analysis of the Nivomat, air spring and hydropneupatic level control systems						
1	Level control with stationary vehicle ***(Stationary-vehicle control)***	Level adjustment only possible when axles excited during driving	*1*	possible	*4*	possible	*4*
2	***Supply of external energy***	not required	*4*	electrically driven compressor, 300 - 400 W	*1*	pump driven by vehicle engine/ electrically driven hydraulic unit 500 – 600 W	*1*
3	***Control time*** for reaching level position	within starting distance (800 – 1,500 m), approx. 60 s	*1*	supply of compressible air, 20 - 40 s	*3*	supply of incompressible oil, 10 - 30 s	*4*
4	Number of ***system components***	Nivomat only (accumulator integrated)	*4*	air spring (possibly assembly with shock absorber) compressor, valves, pipes, cables, travels sensor(s), controller	*2*	suspension cylinder, accumulator, oil, pump, valves, pipes, reservoir, cables, travel sensor(s), controller	*1*
5	***Installation space*** for the level control element on the ***axle***	OD 60, 63, 72 mm AG 50, 58, 64 mm NG	*3*	OD of air bellows 75 - 130 mm	*1*	OD 40, 50 mm	*4*
6	***Installation space*** for ***system*** components	not required	*4*	required	*2*	required	*1*
7	***System weight***	5.4 - 7 kg	*4*	12 - 16 kg	*2*	15 - 20 kg	*1*
8	Influence on ***vibrational comfort***	according to design	*4*	according to design	*4*	according to design	*4*
9	***Rolling comfort***	friction hysteresis	*3*	roll-bellows hysteresis	*3*	a high-pressure seal	*4*
10	***Compensation*** of an asymmetrical ***load*** distribution	separate control of the level control elements (right/left)	*4*	generally separate control of the air springs on an axle	*4*	generally common control of the suspension cylinders of an axle, separate control possible (4)	*1*
11	Suppression of undesirable ***control processes*** (cornering, single obstacles)	not possible (and generally not required)	*1*	generally separate control of the air springs on an axle	*4*	generally common control of the suspension cylinders of an axle, separate control possible (4)	*3*
12	***System installation*** in vehicle	very easy (like shock absorber)	*4*	complex	*2*	complex	*1*
13	Exchange, maintenance, repair (***Service***)	very easy (like shock absorber)	*4*	exchange of the failing components with pneumatic and/or electric interfaces	*2*	exchange of the failing components with hydraulic and/or electric interfaces / ventilation	*1*
14	***Reliability***	proven	*4*	proven	*4*	proven	*4*
15	***Effort involved when retrofitting***	very easy (like shock absorber)	*4*	retrofitting may be possible	*2*	retrofitting generally not possible	*1*
16	***System expandability***, additional functions	limitted (CDC, break power regulator connection)	*2*	possible	*4*	possible	*4*
17	***Hours needed for prim. develop.***	1,500 hrs min.	*4*	3,000 hours min.	*1*	3,000 hours min.	*1*
18	***Duration of primary development***	1 year min.	*4*	2 years min.	*1*	2 years min.	*1*
19	***System price***	approx. DM 300	*4*	approx. DM 500	*2*	approx. DM 600	*1*

Note:
The comparison was made for partially loaded rear axle level control systems, i.e. an additional steel spring is installed as well.

Fig. 11: Comparison of systems

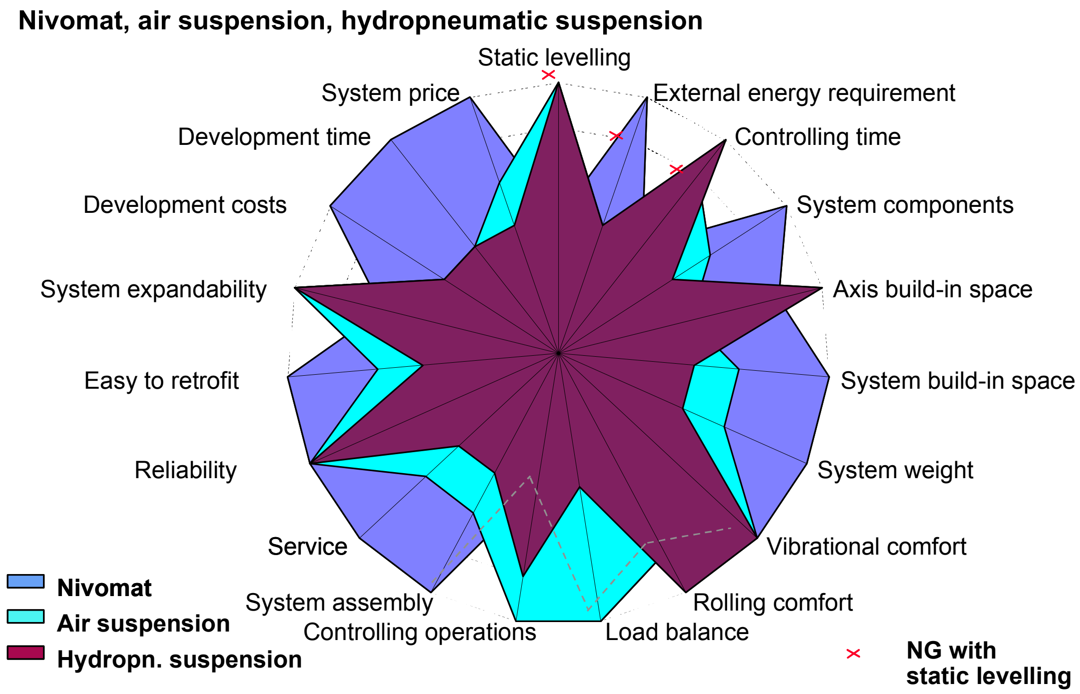


Fig. 12: Comparison of systems

9. Outlook

9.1 New Nivomat Generation

An essential objective of the development of the New Nivomat generation (**Fig. 13**), which is going into production now, was to reduce the space required for the Nivomat applications, i.e. to get closer to the space requirement of conventional shock absorbers.

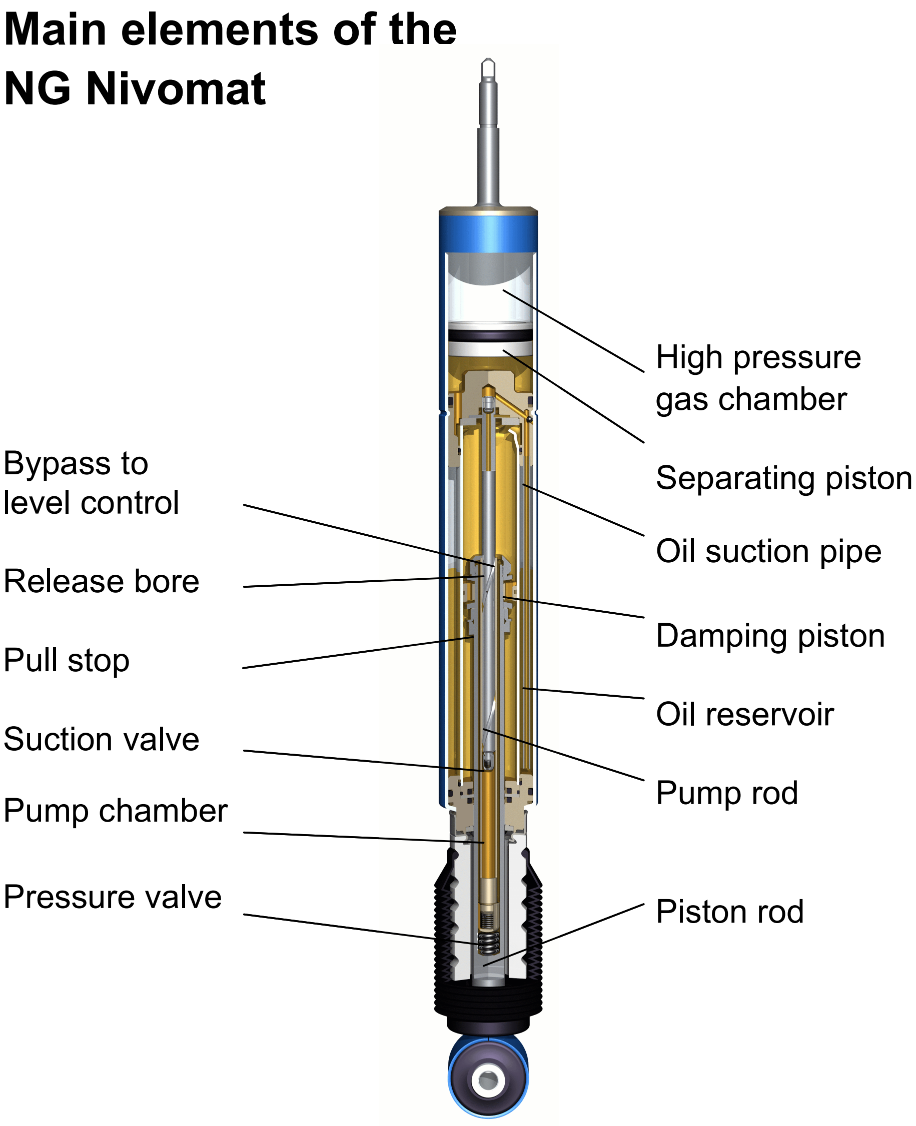


Fig. 13: New Nivomat generation

The fundamental difference in the design of the devices as compared to the present Nivomat generation is that the enclosed volumes required are no longer arranged radially but lengthwise. This arrangement makes it possible to achieve the required separation between gas and oil through a separating piston arranged in the high-pressure accumulator. The minimum diameter of the outer tube can thus be reduced to 54 mm. Should the required space in the lengthwise direction of the device not be available, the necessary volume can also be accommodated in an external separating-piston accumulator, which is mounted in a suitable position on the device.

9.2 Static levelling

An additional pump can be adapted to the Nivomat for special application purposes. This electrically driven pump is of a piston pump design and makes it possible to adjust the optimum level whilst the vehicle is still stationary. The auxiliary pump can be used for separating piston and diaphragm devices. It is activated for a short time, for example when starting the car, and needs approx. 60 seconds to bring the fully loaded vehicle to the required level.

This does not require an addional height sensor, since one is already incorporated into the Nivomat design. It prevents further pumping when the level has been reached in the same manner as in the standard device.

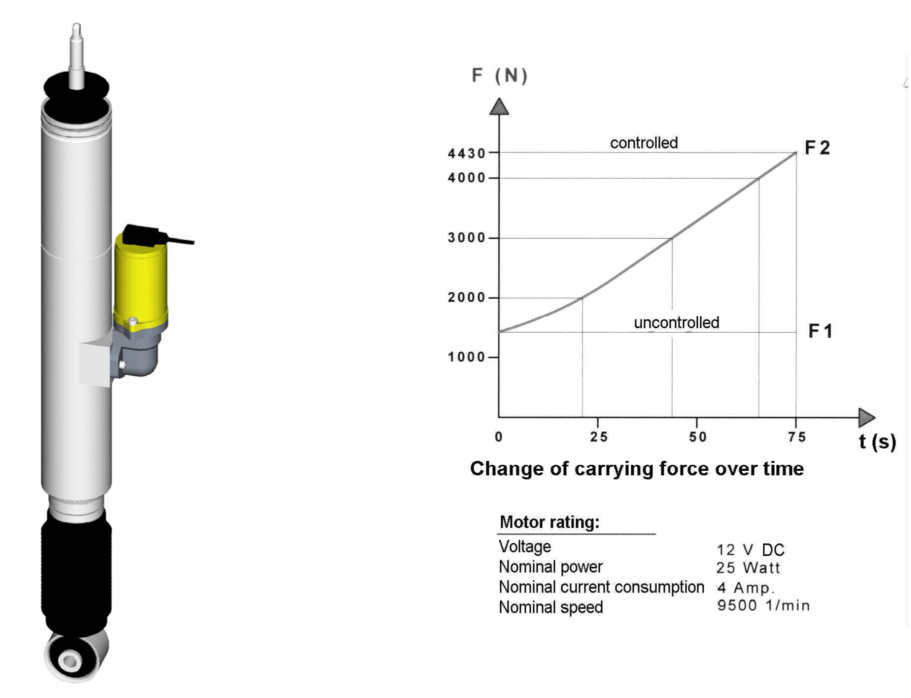


Fig. 14: Nivomat with static levelling

9.3 Nivomat with CDC

The Nivomat can be integrated into a vehicle's SACHS CDC (Continuous Damping Control) system. In this case, only an adapted external CDC valve is to be used, as the interior is required for the pump components.

Damping on the tension and pressure sides only occurs in the CDC valve. To ensure a unidirectional oil flow in the valve during tension and compression strokes, an oil guide pipe and a check valve are additionally installed on the piston and in the bottom of the cylinder tube. The CDC valve used is a special variant that has been adapted to the high pressures involved in the Nivomat system.

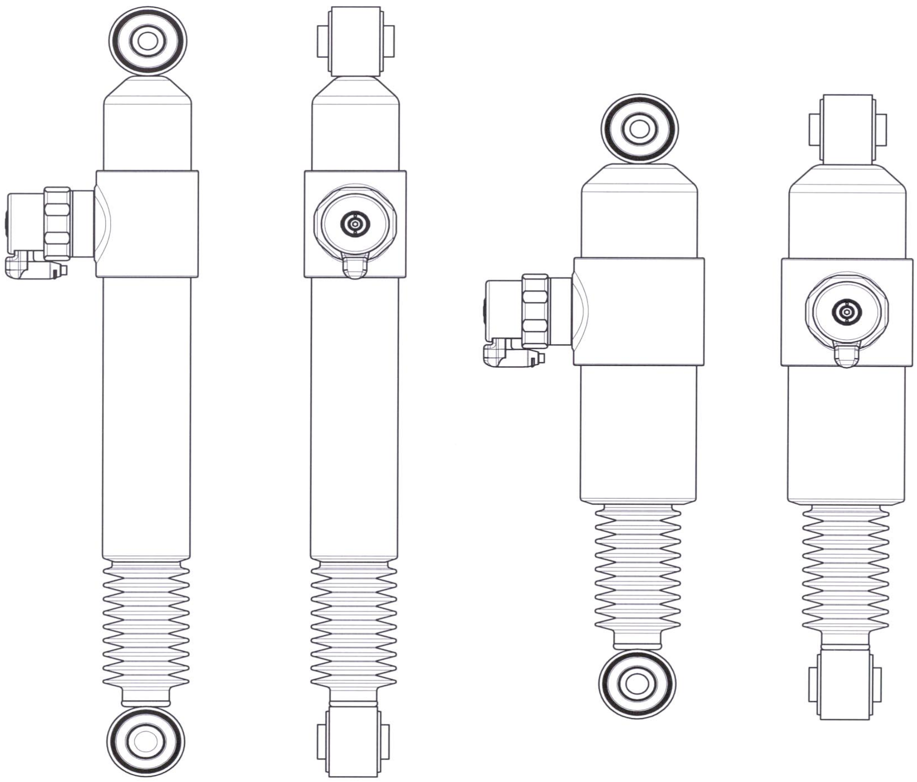


Fig. 15: Nivomat with CDC valve

9.4 Lightweight design

The chassis design of so-called lightweight vehicles, i.e. vehicles which often exhibit extreme payload ratios, poses a special problem since the necessary compromise between driving comfort and driving safety is usually most noticeable here. The realization of acceptable handling characteristics with the weight being low is hardly possible with conventional spring-and-shock absorber systems. Here, the Nivomat with its inherent load-dependent damping behaviour, designed as a fully loaded level control element, has special advantages. Special lightweight versions have been developed for the application in such vehicles. The weight per unit can be reduced to approx. 1 kg by the use of typical lightweight materials.

10. Summary

The Nivomat is currently the most common passenger car level control system in Europe.

The Nivomat owes this to its special characteristics:

- Compactness (pump, regulator, accumulator, reservoir and damping in one housing)
- Additional load-sensitive damping
- No hydraulic lines or electric cables
- No adjustment of an additional height level regulator is necessary
- No electric energy or motor is required
  (Required energy is generated from kinetic energy of the wheels)
- Environmentally friendly since no energy in the form of fuel is consumed
- Easy to install and to retrofit
- Lighter and less expensive as compared to other level control systems.

So far there is a variety of vehicle applications especially for medium-size cars, estates, vans and saloons, which give evidence for the device's wide range of applications.

The new Nivomat generation, which offers even more favourable conditions with regard to size and weight, will make level control also attractive for vehicles of the smaller classes. Since their kerb weight-to-payload ratios are usually even more unfavourable than those of the higher classes, it is also possible to achieve considerable comfort and driving security improvements for these vehicles by using a Nivomat-controlled axle.