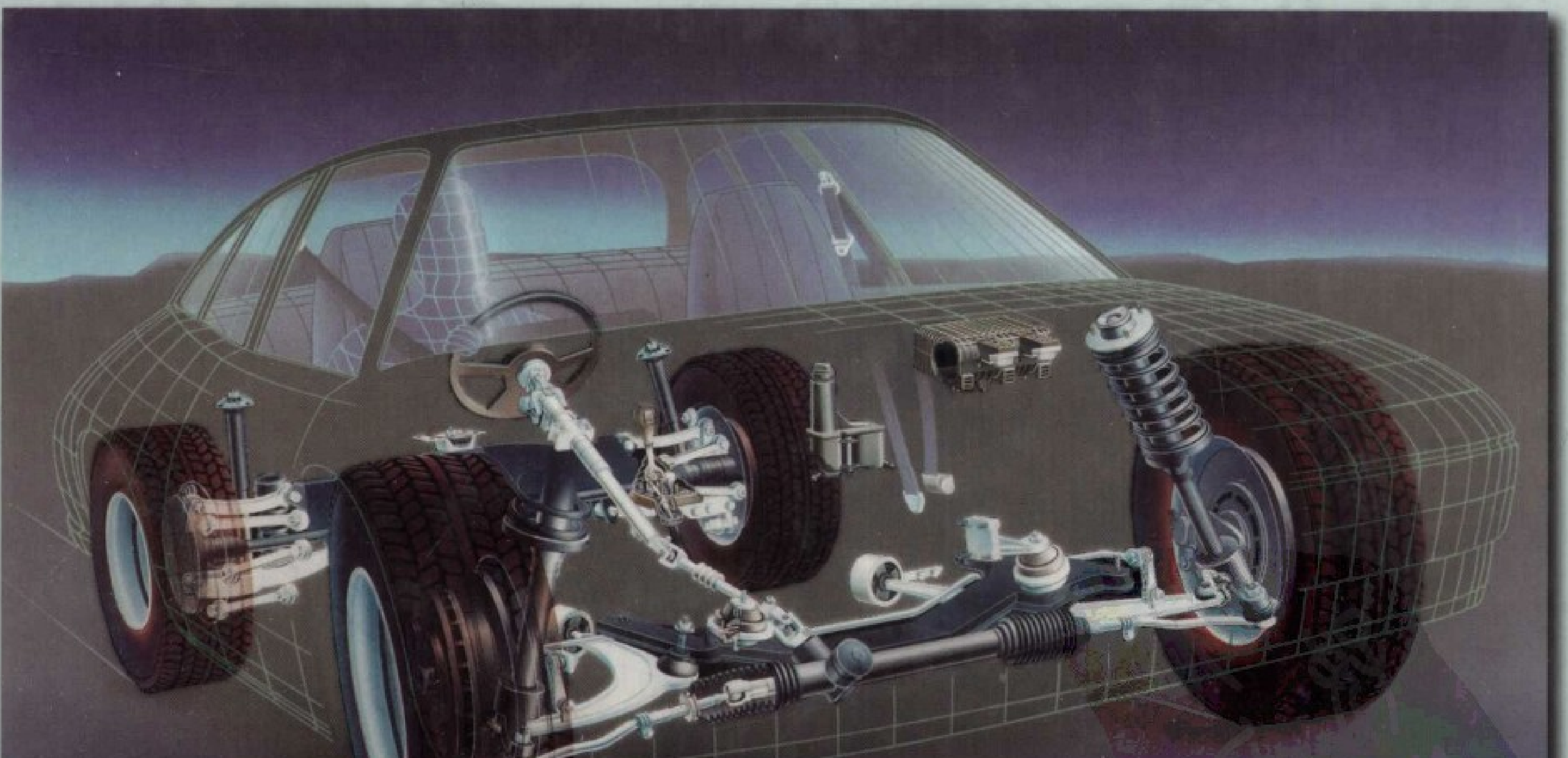
ENGINEERING PRINCIPLES SECOND EDITION

The Automotive Chassis



J. REIMPELL H.STOLL J.W.BETZLER

ENGINEERING

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ENGINEERING PRINCIPLES SECOND EDITION

Jörnsen Reimpell, Helmut Stoll and **Jürgen W Betzler**

The second English edition of this classic text (published simultaneously by the German publishers, Vogel Buchverlag) has been thoroughly revised to take into account the latest technology. As with the first edition, descriptions are clear and easy to understand. There are numerous example designs and calculations throughout the text, and 434 illustrations are included to relate basic engineering principles to the particular requirements of the chassis and of vehicle mechanics.

Entirely new material on total vehicle and suspension design is incorporated, and areas which are covered include the platform concept, four wheel drive technology, and suspension design of the most up-to-date vehicles. Additionally, it now fully conforms to the international standards ISO 8855 and SAE J 670.

This second edition of **The Automotive Chassis** is essential reading for component and system engineers in both higher education and industry as well as for non-specialists who need to gain an understanding of the field. The book provides a clearly structured overview of chassis technology - from the requirements and design of tyres through axle kinematics to vehicle steering as well as springing and damper systems.

Prof. Dipl.-Ing. **Jörnsen Reimpell** lectured in the field of automotive engineering at the University of Applied Science Cologne for many years, and is now a freelance consultant. Dipl.-Ing. **Helmut Stoll** is a chief engineer at General Motors (Adam Opel AG). Prof. Dr.-Ing. **Jürgen W Betzler** is professor for chassis/simulation technology at the University of Applied Science Cologne.

R-300

ISBN 0-7680-0657-0

9 780768 006575

The Automotive Chassis: Engineering Principles

SECOND EDITION

Chassis and vehicle overall
Wheel suspensions and types of drive
Axle kinematics and elastokinematics
Steering – Springing – Tyres
Construction and calculations advice

Prof. Dipl.-Ing. Jörnsen Reimpell
Dipl.-Ing. Helmut Stoll
Prof. Dr.-Ing. Jürgen W. Betzler

Translated from the German by AGET Limited

SAE INTERNATIONAL®

Published on behalf:
Society of Automotive Engineers, Inc.
400 Commonwealth Drive
Warrendale, PA 15096-0001

Butterworth-Heinemann
An imprint of Elsevier Science
Linacre House, Jordan Hill, Oxford OX2 8DP
225 Wildwood Avenue, Woburn, MA 01801-2041

Original copyright 1986 Vogel-Buchverlag, Würzburg
Fourth German edition published by Vogel-Buchverlag, Würzburg 1999
First English edition published by Arnold 1996
Second edition published by Butterworth-Heinemann 2001
Reprinted 2002

Library of Congress Cataloguing in Publication Data
A catalogue record for this book is available from the Library of Congress

ISBN 0 7680 0657 0
Order number R-300

Society of Automotive Engineers, Inc.
400 Commonweatlth Drive
Warrendale, PA 15096-0001 USA
Phone: (724) 776-4841
Fax: (724) 776-5760
E-mail: publications@sae.org
http://www.sae.org

Composition by Cambrian Typesetters, Frimley, Surrey
Printed and bound in Great Britain by Biddles Ltd, Guildford & Kings Lynn

Preface

This translation of the fourth German edition is published by Butterworth-Heinemann as the second English edition of *The Automotive Chassis.*

We are fortunate to have Prof. Dr.-Ing. Jürgen W. Betzler as co-author; he has been an expert in the field of chassis/simulation technology and design studies at the University of Cologne since 1994. Jointly, we revised *The Automotive Chassis: Engineering Principles* to include a large number of technical innovations.

The clear and easy descriptions, many example designs and calculations and the inclusion of 434 illustrations and tables are easily understood and have, over the years, proven to be the best way of imparting information.

The authors' many years of experience in chassis engineering support the practical bias and will help engineers, inspectors, students and technicians in companies operating in the automotive industry and its suppliers to understand the context. The comprehensive index of key words and numerous cross-references make this book an invaluable reference work.

We should like to thank Dipl.-Ing. Achim Clasen for collating the test results in the Automotive Engineering Laboratory at the Technical University in Cologne and Sabine Jansen M.A. for her hard work in converting the symbols.

Cologne/Rösrath

Jörnsen Reimpell
Helmut Stoll
Jürgen W. Betzler

Contents

1

Types of suspension and drive

This chapter deals with the principles relating to drives and suspensions.

1.1 General characteristics of wheel suspensions

The suspension of modern vehicles need to satisfy a number of requirements whose aims partly conflict because of different operating conditions (loaded/unloaded, acceleration/braking, level/uneven road, straight running/cornering).

The forces and moments that operate in the wheel contact area must be directed into the body. The kingpin offset and disturbing force lever arm in the case of the longitudinal forces, the castor offset in the case of the lateral forces, and the radial load moment arm in the case of the vertical forces are important elements whose effects interact as a result of, for example, the angle of the steering axis.

Sufficient vertical spring travel, possibly combined with the horizontal movement of the wheel away from an uneven area of the road (kinematic wheel) is required for reasons of *ride comfort*. The recession suspension should also be compliant for the purpose of reducing the rolling stiffness of the tyres and short-stroke movements in a longitudinal direction resulting from the road surface (longitudinal compliance, Fig. 1.1), but without affecting the development of lateral wheel forces and hence steering precision, for which the most rigid wheel suspension is required. This requirement is undermined as a result of the necessary flexibility that results from disturbing wheel movements generated by longitudinal forces arising from driving and braking operations.

For the purpose of ensuring the optimum *handling characteristics* of the vehicle in a steady state as well as a transient state, the wheels must be in a defined position with respect to the road surface for the purpose of generating the necessary lateral forces. The build-up and size of the lateral wheel forces are determined

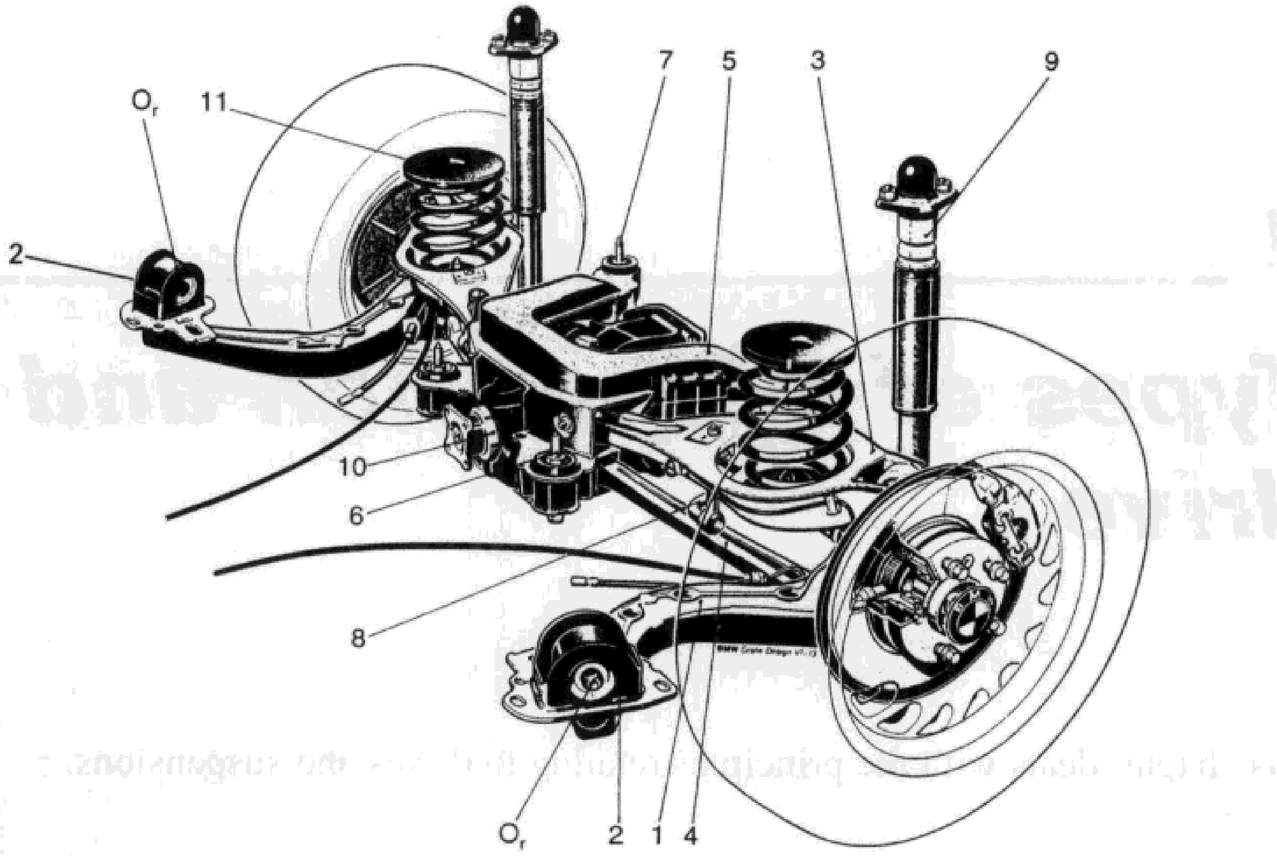

Fig. 1.1 A multi-link rear axle – a type of suspension system which is progressively replacing the semi-trailing arm axle, and consists of at least one trailing arm on each side. This arm is guided by two (or even three) transverse control arms (Figs 1.62 and 1.77). The trailing arm simultaneously serves as a wheel hub carrier and (on four-wheel steering) allows the minor angle movements required to steer the rear wheels. The main advantages are, however, its good kinematic and elastokinematic characteristics.

BMW calls the design shown in the illustration and fitted in the 3-series (1997) a 'central arm axle'. The trailing arms 1 are made from GGG40 cast iron; they absorb all longitudinal forces and braking moments as well as transfering them via the points 2 – the centres of which also form the radius arm axes (Figs 3.158 and 3.159) – on the body. The lateral forces generated at the centre of tyre contact are absorbed at the subframe 5, which is fastened to the body with four rubber bushes (items 6 and 7) via the transverse control arms 3 and 4. The upper arms 3 carry the minibloc springs 11 and the joints of the anti-roll bar 8. Consequently, this is the place where the majority of the vertical forces are transferred between the axle and the body.

The shock absorbers, which carry the additional polyurethane springs 9 at the top (Fig. 5.50), are fastened in a good position behind the axle centre at the ends of the trailing arms. For reasons of noise, the differential 10 is attached elastically to the subframe 5 at three points (with two rubber bearings at the front and one hydro bearing at the back). When viewed from the top and the back, the transverse control arms are positioned at an angle so that, together with the differing rubber hardness of the bearings at points 2, they achieve the desired elastokinematic characteristics. These are:

- toe-in under braking forces (Figs 3.64 and 3.82);
- lateral force compliance understeer during cornering (Figs 3.79 and 3.80);
- prevention of torque steer effects (see Section 2.10.4);
- lane change and straight running stability.

For reasons of space, the front eyes 2 are pressed into parts 1 and bolted to the attachment bracket. Elongated holes are also provided in this part so toe-in can be set. In the case of the E46 model series (from 1998 onwards), the upper transverse arm is made of aluminium for reasons of weight (reduction of unsprung masses).

by specific toe-in and camber changes of the wheels depending on the jounce and movement of the body as a result of the axle kinematics (roll steer) and operative forces (compliance steer). This makes it possible for specific operating conditions such as load and traction to be taken into consideration. By establishing the relevant geometry and kinematics of the axle, it is also possible to prevent the undesirable diving or lifting of the body during braking or accelerating and to ensure that the vehicle does not exhibit any tendency to oversteer and displays predictable transition behaviour for the driver.

Other requirements are:

- independent movement of each of the wheels on an axle (not guaranteed in the case of rigid axles);
- small, unsprung masses of the suspension in order to keep wheel load fluctuation as low as possible (important for driving safety);
- the introduction of wheel forces into the body in a manner favourable to the flow of forces;
- the necessary room and expenditure for construction purposes, bearing in mind the necessary tolerances with regard to geometry and stability;
- ease of use;
- behaviour with regard to the passive safety of passengers and other road users;
- costs.

The requirements with regard to the steerability of an axle and the possible transmission of driving torque essentially determine the design of the axis.

Vehicle suspensions can be divided into rigid axles (with a rigid connection of the wheels to an axle), independent wheel suspensions in which the wheels are suspended independently of each other, and semi-rigid axles, a form of axle that combines the characteristics of rigid axles and independent wheel suspensions.

On all rigid axles (Fig. 1.23), the axle beam casing also moves over the entire spring travel. Consequently, the space that has to be provided above this reduces the boot at the rear and makes it more difficult to house the spare wheel. At the front, the axle casing would be located under the engine, and to achieve sufficient jounce travel the engine would have to be raised or moved further back. For this reason, rigid front axles are found only on commercial vehicles and four-wheel drive, general-purpose passenger cars (Figs 1.3 and 1.4).

With regard to independent wheel suspensions, it should be noted that the design possibilities with regard to the satisfaction of the above requirements and the need to find a design which is suitable for the load paths, increase with the number of wheel control elements (links) with a corresponding increase in their planes of articulation. In particular, independent wheel suspensions include:

- Longitudinal link and semi-trailing arm axles (Figs 1.13 and 1.15), which require hardly any overhead room and consequently permit a wide luggage space with a level floor, but which can have considerable diagonal springing.
- Wheel controlling suspension and shock-absorber struts (Figs 1.8 and 1.57), which certainly occupy much space in terms of height, but which require little space at the side and in the middle of the vehicle (can be used for the engine

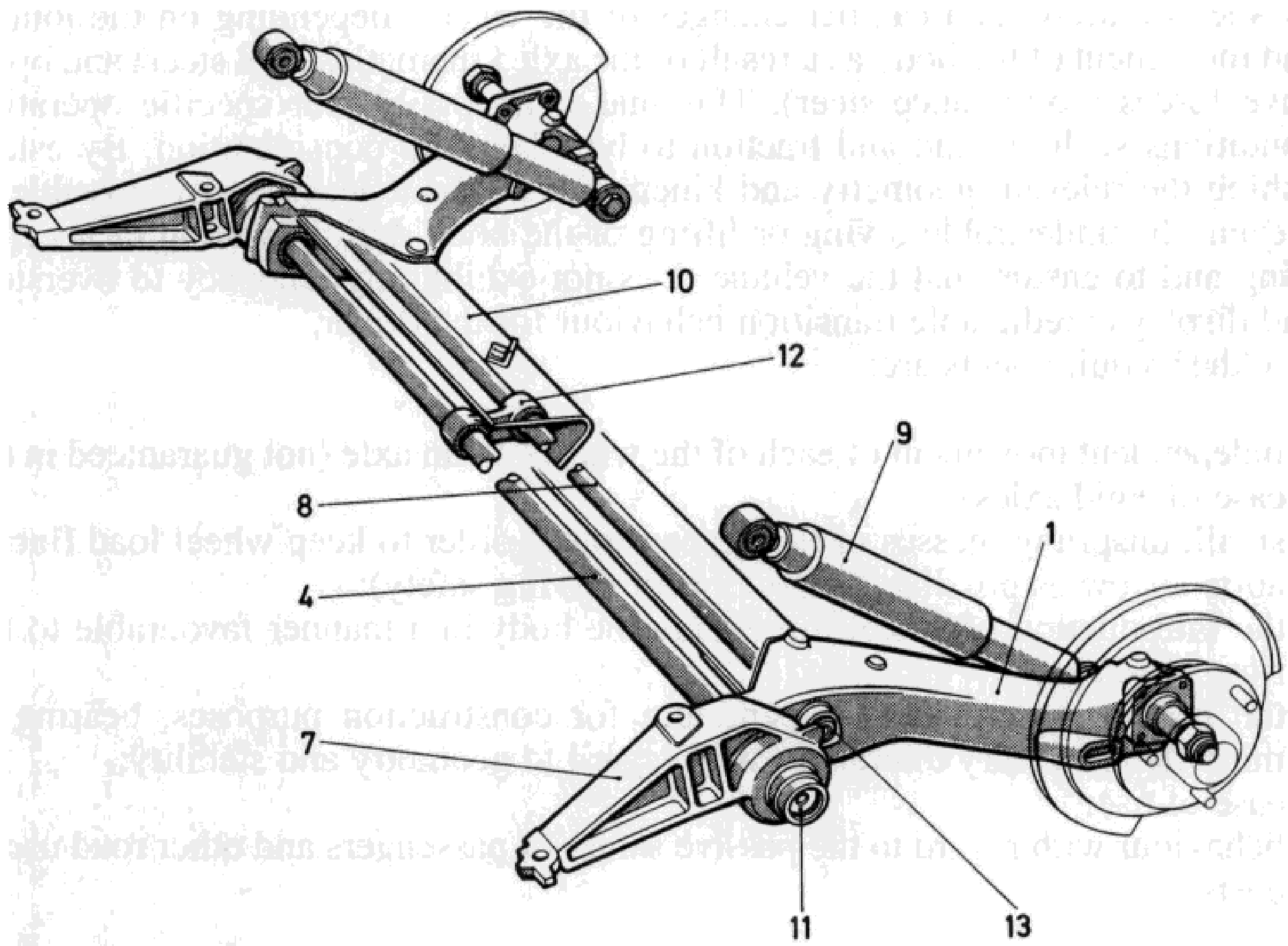

Fig. 1.2 An extremely compact four-bar twist beam axle by Renault, with two torsion bar springs both for the left and right axle sides (items 4 and 8). The V-shape profile of the cross-member 10 has arms of different lengths, is resistant to bending but less torsionally stiff and absorbs all moments generated by vertical, lateral and braking forces. It also partially replaces the anti-roll bar.

At 23.4 mm, the rear bars 8 are thicker than the front ones (Ø 20.8 mm, item 4). On the outside, part 8 grips into the trailing links 1 with the serrated profile 13 and on the inside they grip into the connector 12. When the wheels reach full bump, a pure torque is generated in part 12, which transmits it to the front bars 4, subjecting them to torsion. On the outside (as shown in Fig. 1.63) the bars with the serrated profile 11 grip into the mounting brackets 7 to which the rotating trailing links are attached. The pivots also represent a favourably positioned pitch centre O_r (Fig. 3.159). The mounting brackets (and therefore the whole axle) are fixed to the floor pan with only four screws.

On parallel springing, all four bars work, whereas on reciprocal springing, the connector 12 remains inactive and only the thick rear bars 8 and the cross-member 10 are subject to torsion.

The layout of the bars means soft body springing and high roll stability can be achieved, leading to a reduction of the body roll pitch during cornering.

To create a wide boot without side encroachments, the pressurized monotube shock absorbers 9 are inclined to the front and therefore are able to transmit forces upwards to the side members of the floor pan.

or axle drive) and determine the steering angle (then also called McPherson suspension struts).

- Double wishbone suspensions (Fig. 1.7).
- Multi-link suspensions (Figs 1.1, 1.18 and 1.19), which can have up to five guide links per wheel and which offer the greatest design scope with regard to

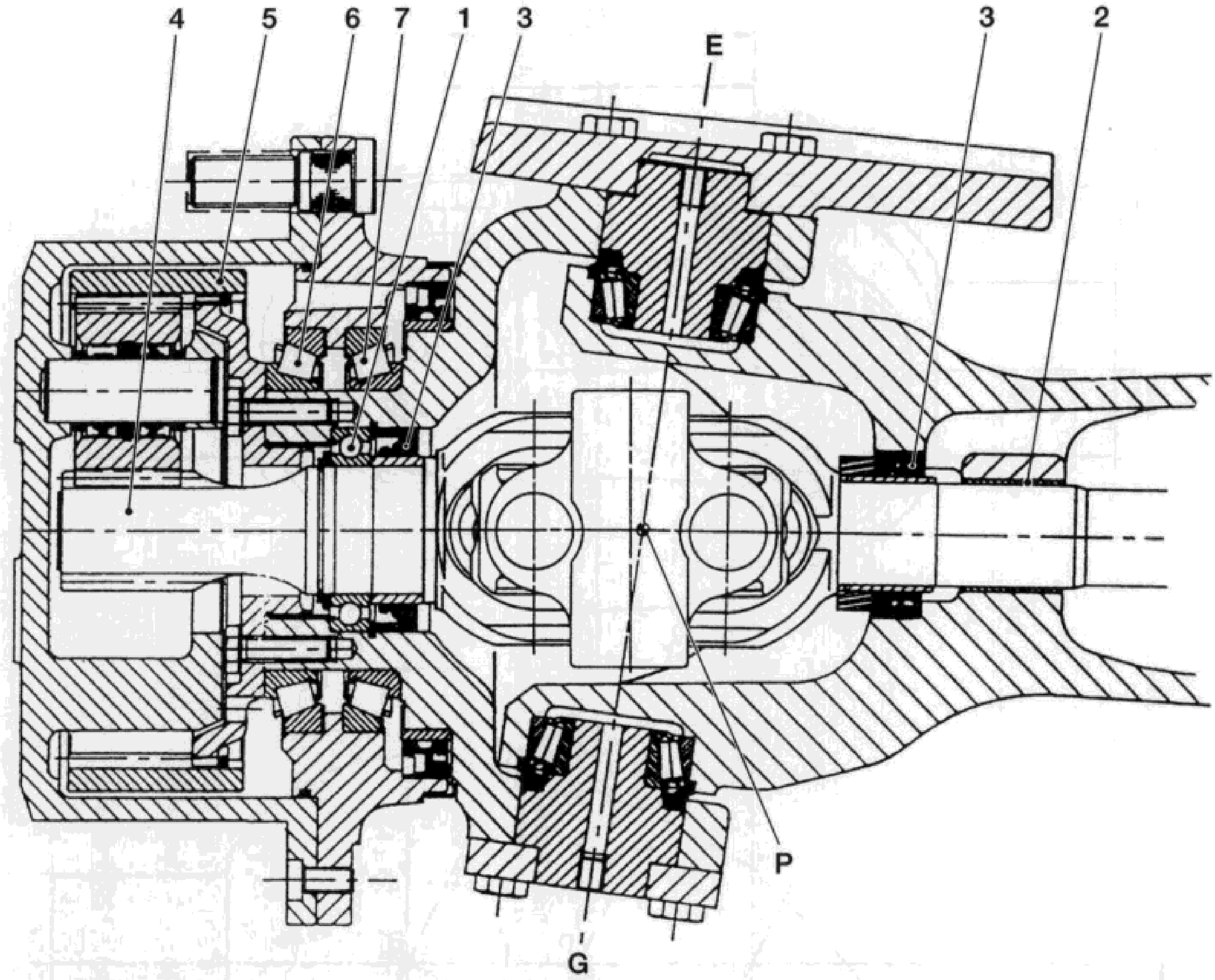

Fig. 1.3 Driven, rigid steering axle with dual joint made by the company GKN – Birfield AG for four-wheel drive special-purpose vehicles, tractors and construction machinery.

The dual joint is centred over the bearings 1 and 2 in the region of the fork carriers; these are protected against fouling by the radial sealing rings 3. Bearing 1 serves as a fixed bearing and bearing 2 as a movable bearing. The drive shaft 4 is also a sun gear for the planetary gear with the internal-geared wheel 5. Vertical, lateral and longitudinal forces are transmitted by both tapered-roller bearings 6 and 7. Steering takes place about the steering axis EG.

the geometric definition of the kingpin offset, pneumatic trail, kinematic behaviour with regard to toe-in, camber and track changes, braking/starting torque behaviour and elastokinematic properties.

In the case of twist-beam axles (Figs 1.2, 1.31 and 1.58), both sides of the wheels are connected by means of a flexurally rigid, but torsionally flexible beam. On the whole, these axles save a great deal of space and are cheap, but offer limited potential for the achievement of kinematic and elastokinematic balance because of the functional duality of the function in the components and require the existence of adequate clearance in the region of the connecting beam. They are mainly used as a form of rear wheel suspension in front-wheel drive

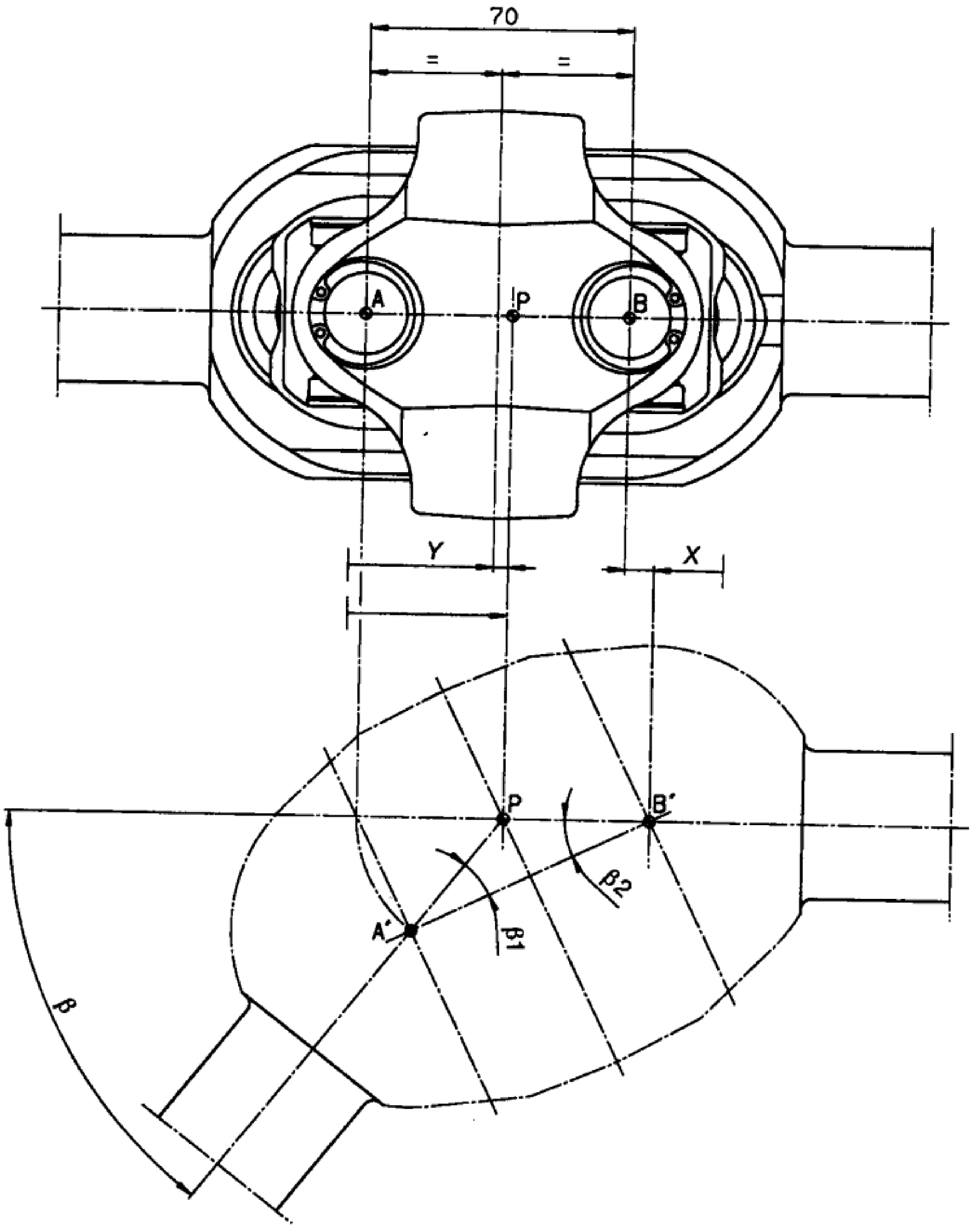

Fig. 1.4 Top view of the dual joint (Fig. 1.3). The wheel end of the axle is turned about point P in the middle of the steering pivot during steering. The individual joints are constrained at points A and B so that point A is displaced to position A′, P is displaced to P′ and B is displaced along the drive axle by the distance *X* to B′. In order to assimilate the variable bending angle *β* resulting from the longitudinal displacement of point B, the mid-point of the joint P is displaced by the distance *Y*. The adjustment value *Y* depends on the distance between the joints and the steering angle at which constant velocity is to exist. Where large steering angles can be reached (up to 60°), there should be constant velocity at the maximum steering angle.

The adjustment value *Y* and the longitudinal displacement *X* should be taken into consideration in the design of the axle.