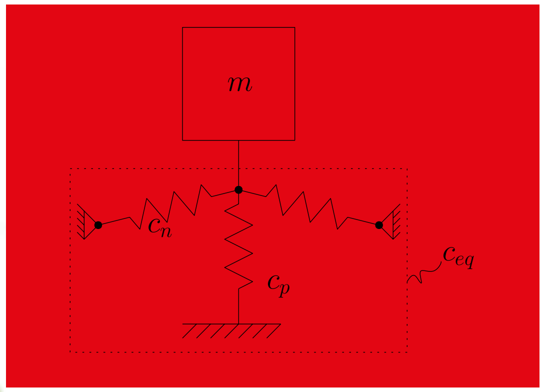
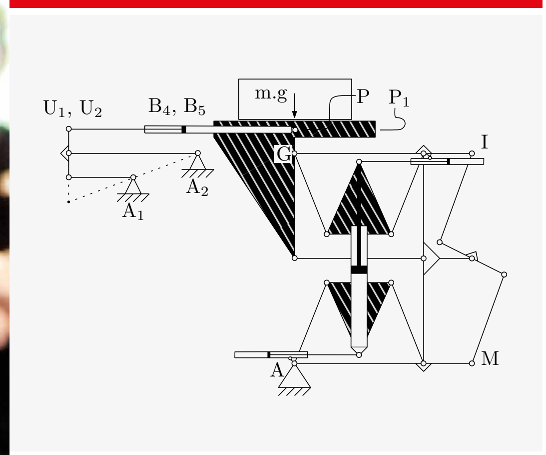
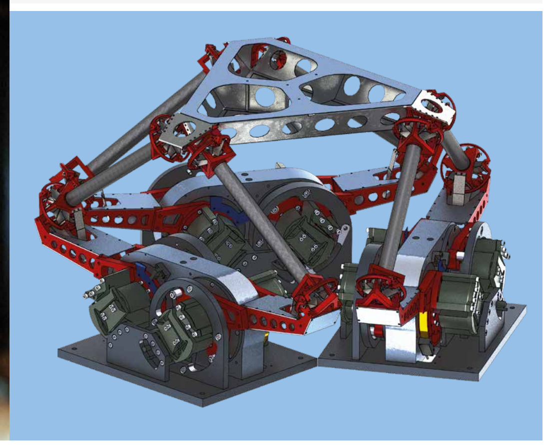
MIKRONIEK

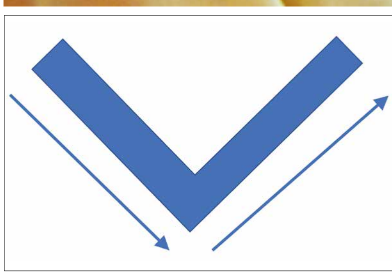
PROFESSIONAL JOURNAL ON PRECISION ENGINEERING

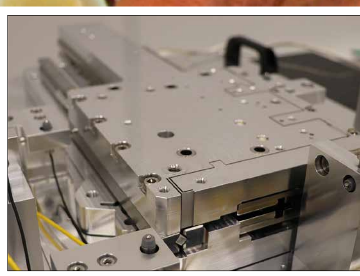
2019 (VOL. 59) ISSUE 3

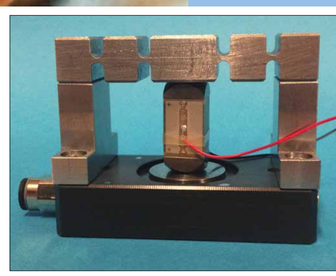












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DSPE

MIKRONIEK IS A PUBLICATION OF THE DUTCH SOCIETY FOR PRECISION ENGINEERING WWW.DSPE.NL

PUBLICATION INFORMATION

Objective
Professional journal on precision engineering and the official organ of DSPE, the Dutch Society for Precision Engineering. Mikroniek provides current information about scientific, technical and business developments in the fields of precision engineering, mechatronics and optics. The journal is read by researchers and professionals in charge of the development and realisation of advanced precision machinery.

DSPE
YOUR PRECISION PORTAL

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+31 (0)40 – 251 99 29, info@snep.nl

Subscription
Mikroniek is for DSPE members only.
DSPE membership is open to institutes, companies, self-employed professionals and private persons, and starts at € 80.00 (excl. VAT) per year.

Mikroniek appears six times a year.

ISSN 0026-3699

The main cover photo (featuring Wim van der Hoek, read the article on page 5 ff.) is courtesy of Bart van Overbeeke. The three illustrations on the right, top to bottom, are courtesy of Roy Jacobs (page 22 ff.), Martin Kristelijn (page 12 ff.) and Mark Naves (page 17 ff.), respectively.

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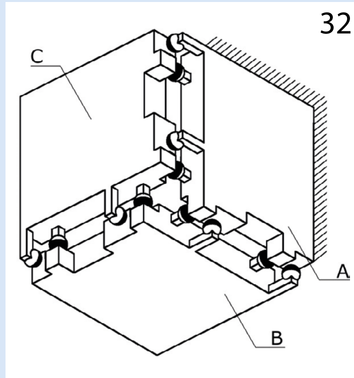
WIM VAN DER HOEK MEMORIAL ISSUE



FEATURES

WIM VAN DER HOEK'S LEGACY

Professor Wim van der Hoek, honourable member of our community of precision engineers, passed away on 12 January 2019.
On many occasions Wim told with characteristic enthusiasm about his childhood and the endless hours he spent playing with Meccano; a popular toy in the 1920s and 1930s. There was no doubt that Wim would study mechanical engineering in Delft. In 1949, he graduated at Delft University of Technology and joined N.V. Philips Gloeilampenfabrieken in Eindhoven, as a mechanical engineer in Production Engineering. At that time, most high-speed mass-production machines were cam-operated; they had to achieve a high degree of repeatability in order to meet the product requirements. Engineers paid considerable attention to the accuracy of movement and positioning of mechanisms.

Wim van der Hoek was the first to emphasise the dynamics of cam mechanisms as a source of positional errors in high-speed production machinery. He developed a simple design tool by means of which the positional error – due to the dynamics of cams and the backlash – could be estimated in the drawing office. He also suggested improvements in the design of mechanisms from a dynamics point of view, involving lightweight, high stiffness and the avoidance of backlash. These suggestions, presented as design principles, turned out to be useful for a wider range of applications. More examples were added with relevancy for the generic issue of positional accuracy, which concerned topics such as flexures, micromanipulators, kinematic constraints, friction and hysteresis, rolling contact and energy management.
As a scientific advisor to the Philips board of directors, Wim was one of the founding fathers of the Philips Centre for Manufacturing Technology (*Centrum voor Fabricage Technologie*, CFT), the company's laboratory for the development of production processes and machinery. There he was appointed as manager of the Mechanics and Mechanisms section. In this role Wim developed to become an inspiring role model for many (starting and experienced) engineers.

From 1962 onwards Wim was a part-time professor at Eindhoven University of Technology in the chair of Design and Construction of Mechanisms. He started to collect design principles in his lecture notes called "The Devil's Picture Book" (*Des Duivels Prentenboek*, DDP). Although each individual picture was suitable for direct application, it was primarily intended as an invitation to the engineers to think about and – if possible – to make a better design. The DDP content was continuously updated with examples from the field throughout his professional life. New areas of application were added in order to keep up with the advancing technology of precision engineering. DDP became popular, amongst students and within industry.
After Wim's retirement in 1994, the development of DDP continued, led by his successors at the three Dutch universities of technology and in the Netherlands' precision industry. It is hard to imagine what the high-tech precision industry in this country would currently look like without DDP.

Wim also paid attention to the design process itself. His inaugural lecture in 1962 was entitled "Constructing as Confrontation between Critique and Creation" (*Construeren als Confrontatie tussen Critiek en Creatie*). He considered creativity to be a unique property of humans and encouraged its use. In his view, the results of creativity needed to be criticised by the application of scientific tools. He liked to be a participant in the confrontation between the two approaches. Wim definitely was not the magician who presented solutions by heart; he welcomed every contribution of participants and tools to the innovation process. As he explained: "Designing is playing with Meccano and getting a salary on top of it." We will remember his inspiring enthusiasm, his scientific approach, his craftsmanship and his love of people.

We would like to extend our most sincere condolences to Mrs. Van der Hoek and the Van der Hoek family.

Rien Koster
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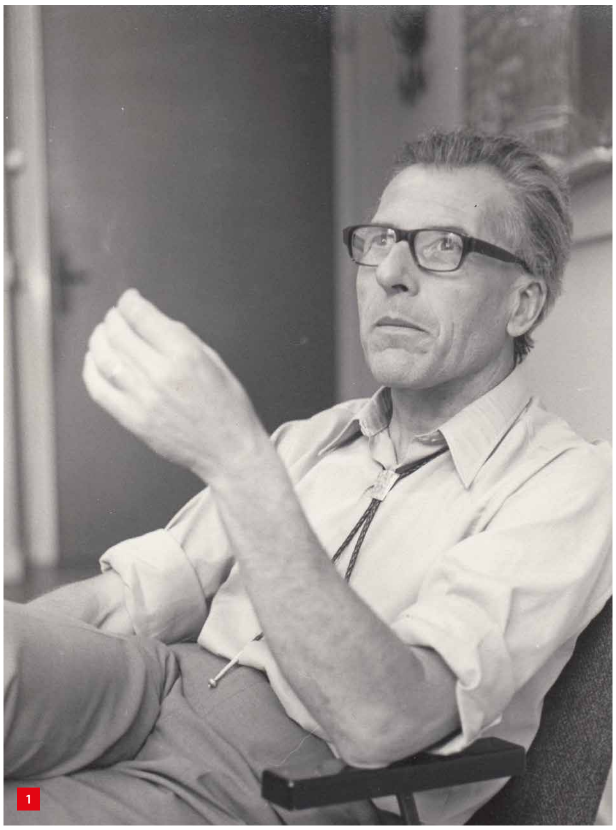
BETWEEN CRITIQUE AND CREATION

Wim van der Hoek died at the beginning of this year at the age of 94. He worked at Philips from 1949 to 1984 and during the period 1961-1984 was part-time professor at the Eindhoven University of Technology. In these positions, he laid the foundation for the critical and creative manner of mechanical engineering design that has driven the Dutch high-tech and manufacturing industries to great heights. This edition of Mikroniek aims to honour his memory with articles about designs in his vein and reflections that build on his ideas. At the end of this year a (Dutch) biography will be published, which will describe and analyse his life, his work and his legacy in detail.



1

Wim van der Hoek.

Wim van der Hoek gained an important formative experience, both in characterological and professional terms, during the Second World War, when he became involved in espionage for the Dutch resistance. On the basis of his secondary school knowledge, he had to interpret intelligence gathered about (the trajectory of) the V2 missiles which the Germans, not far from his then home town of Leiderdorp, fired at London. He thus contributed to the answer to the question whether the V2 was radio-controlled or ballistic; he found the latter to be the case.

It was possibly his first exercise in independent thinking about technical problems and thereby contributing to a greater goal. After the war he discovered that this knowledge had indeed been passed on to the British authorities. His early war experiences and the later awareness of the strategic value of production mechanisation for Philips and Dutch industry led to his decision to always publish in Dutch. This was to prevent the knowledge and ideas that he had generated together with colleagues and students from ending up in foreign hands and being used for military purposes. This sense of social responsibility was a common thread in the rest of his life.
Wim van der Hoek studied mechanical engineering at Delft University of Technology and joined a department of production mechanisation at the industrial giant Philips in Eindhoven in 1949 (Figure 2). There he became involved in Philips Internal Technical Education two years later. With him, the constructor/designer and the lecturer were inextricably in one person united.

2

After graduating from Delft University of Technology, Wim van der Hoek joined a department of production mechanisation at the industrial giant Philips in Eindhoven. (Source: Philips Museum)

EDITOR'S NOTE

The input for this article came from Rien Koster, Jan van Eijk, Piet van Rens, Herman Soemers, Wouter Vogelesang, Frans Geerts, Jos Gunsing, Piet Steeghs, Hein Reinders, Rouke van der Hoek, Lambert van Beukering and others.

He became scientific advisor to the Board of Directors at Philips and as such he was a co-founder of the Philips Centre of Manufacturing Technology (*Centrum voor Fabricage Technologie*, CFT), where he was heading the department of Mechanics and Mechanisms. He acted as a (technical and scientific) advisor for all sections of the Philips group, from the workshop to the board. Hierarchical thinking was alien to him. When a design engineer was 'promoted' to become a manager, Van der Hoek jested: "We have lost him to the management."

Visual thinking

In 1961 he was appointed part-time professor in the chair of Design and Construction in the Department of Mechanical Engineering at Eindhoven University of Technology. He explained his programme in his inaugural speech, in which he answered the question he had raised himself, namely how to teach students to design. "Together with them, searching for inspiration, 'scanning the field for ideas', on one hand, and on the other hand, challenging them to apply their knowledge quickly and logically, and make it accessible. This will help them to start real designing in the sense that I have wanted to elucidate for you today: constructing as a confrontation between critique and creation."

Van der Hoek used this educational approach in his teaching and in his work at Philips. Entering into a confrontation with students or colleagues and staff and preferably letting them create the 'invention' themselves, or letting them formulate the answer to the problem at hand for themselves. He did this mainly by asking a lot of questions, giving positive feedback and acting as a 'visual thinker' avant la lettre.
He called on the (student) designers to visualise for themselves how a construction behaves, how a part of it moves and how it feels under the influence of the occurring forces. This to intuitively understand/feel what is happening and where the bottlenecks lie. For example, how a ball runs in a recirculating ball nut or how a cam mechanism behaves and where the wear or backlash occurs. Of course it was necessary to understand a piece of technology theoretically, but also to physically grasp it and 'get inside it'.

This visual thinking was reflected in his use of language, which was extraordinarily flowery and sometimes 'unparliamentary', even where design and technology were concerned. He was also careful not to use any secret language or too much jargon. He did everything in his power to demythologise his profession with understandable language and to make his reasoning imitable. He also insisted on the importance of words. Describing a design in words causes a designer to consider his own work with a critical distance and wonder whether it could be made smarter.

Illustrative for this approach are the renowned Monday sessions that Van der Hoek held with his students at Eindhoven University of Technology. Together they sat around a table on which a large sheet of yellow drawing paper invitingly lay for sketching and calculations, mutual remarks, spontaneous generation of ideas and everything that came to their minds.

On the one hand, Van der Hoek's approach was based on inventiveness in constructive insight, and on the other hand, on the confrontation of these ideas with descriptive calculations and, where necessary, thorough numerical analysis, drawing on disciplines such as theoretical mechanics, the theory of strength of materials, materials science and control technology, which Van der Hoek described as the 'indispensable auxiliary sciences'. He was in favour of every mechanical engineer building a 'royal household' around him by establishing personal relationships with a 'court physicist', 'court optician', 'court chemist', 'court electrical engineer', etc., in order to be able to quickly compare ideas with them.

Production mechanisation

The construction of machines for production mechanisation was Van der Hoek's field of work at Philips and the source of inspiration for satisfying the duties of his professorship. This generally concerned machines for assembling discrete products, often with feeding, positioning and fixing processes. The production of electron tubes is a representative example in this respect. The tolerated inaccuracies were 1 micrometer or better at speeds of 2,000 to 3,000 products per hour. These machines were usually single pieces and their development always took more time than desired. After such a machine was put into service, development often continued.

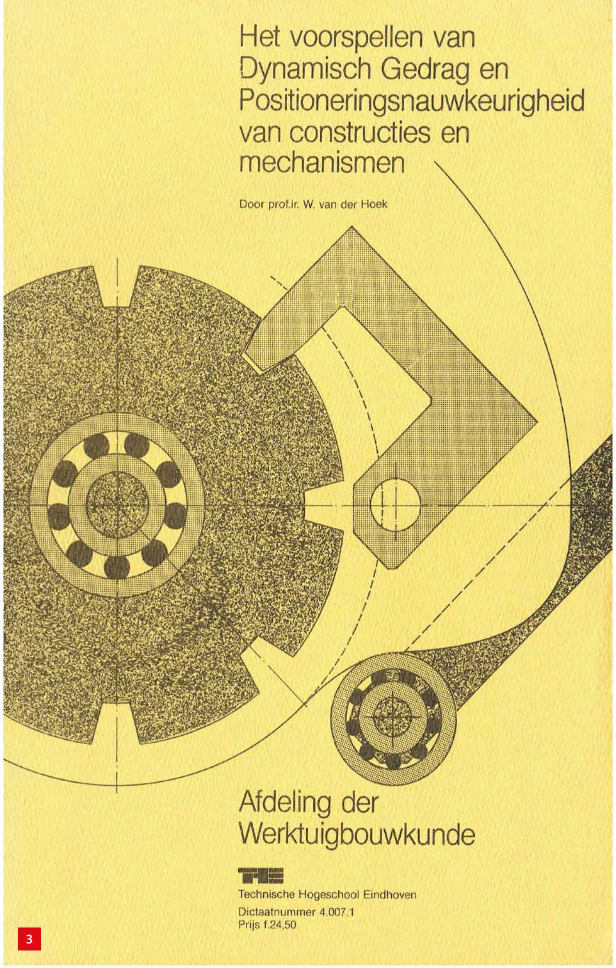
To gain competitive advantage, accuracies had to improve and production speed had to increase. Better control of the accuracy of the movements and the positioning of the tools in the machine had to be obtained, combined with an increase of machine speed. This prompted Wim to focus on the dynamic behaviour of cam mechanisms.

In the first edition of Van der Hoek's lecture notes, a start was made on modelling (cam) mechanisms. The responses of a mechanism based on a simple one-degree-of-freedom model to different incoming movements were evaluated. These responses were due to discontinuities in velocity, caused by backlash, or due to different cam shapes. This led to the insight for responsibly choosing a cam function (preferably without discontinuities in speed or acceleration) and the awareness of the disastrous effect of backlash in the machine on the accuracy of movement and positioning, all under the dominant limitation of the mechanism's natural frequency.

The newly acquired understanding helped in predicting the contribution of dynamics to positioning errors in a mechanism. It also resulted in qualitative and quantitative insight into the mechanical design measures that had to be taken to control these positioning errors. ‘Stiffness’ turned out to be the new design paradigm.

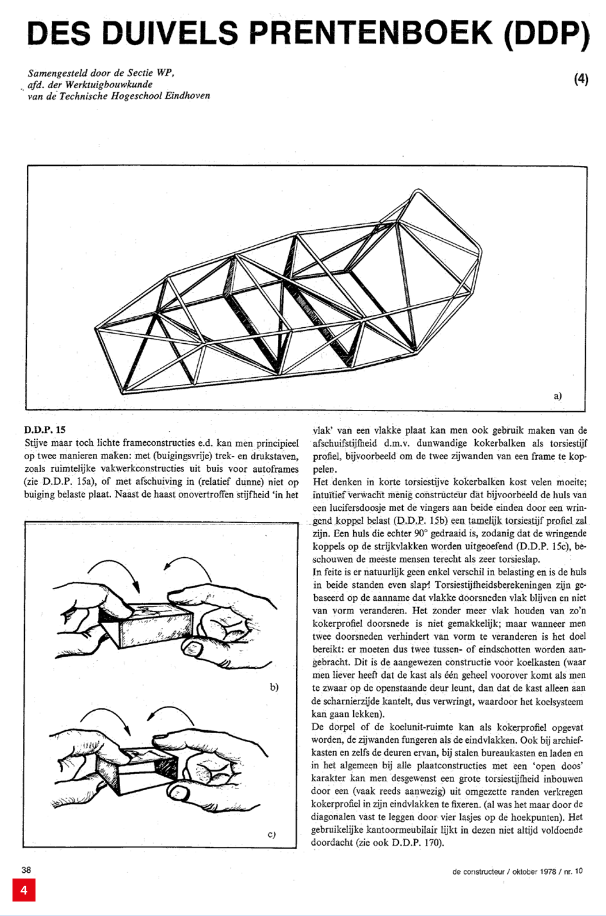
The Devil’s Picture Book

Van der Hoek included all this in his lecture notes (Figure 3), entitled “Predicting Dynamic Behaviour and Positioning Accuracy of constructions and mechanisms” (*Het voorspellen van Dynamisch Gedrag en Positioneringsnauwkeurigheid van constructies en mechanismen*). The first issue was: how do you realise a lightweight structure with high stiffness in order to raise the natural frequency of the mechanism in a fast-moving machine. And secondly: how do you eliminate the backlash? The idea was to show, by means of illustrations with a description, how a compliant mechanism or compliant (frame) structure could be redesigned to exhibit a higher stiffness, how the mass could be reduced in crucial places and how the backlash could be avoided.



3

Van der Hoek’s lecture notes (in Dutch), entitled “Predicting Dynamic Behaviour and Positioning Accuracy of constructions and mechanisms”.



DES DUIVELS PRENTENBOEK (DDP)

Samengesteld door de Sectie WP, afd. der Werktuigbouwkunde van de Technische Hogeschool Eindhoven (4)

a)

D.D.P. 15
Stijve maar toch lichte frameconstructies e.d. kan men principieel op twee manieren maken: met (buigingsvrije) trek- en drukstaven, zoals ruimtelijke vakwerkconstructies uit buis voor autoframes (zie D.D.P. 15a), of met afschuiving in (relatief dunne) niet op buiging belaste plaat. Naast de haast onovertroffen stijfheid ‘in het vlak’ van een vlakke plaat kan men ook gebruik maken van de afschuifstijfheid d.m.v. dunwandige kokerbalken als torsiestijf profiel, bijvoorbeeld om de twee zijwanden van een frame te koppelen.
Het denken in korte torsiestijve kokerbalken kost velen moeite; intuïtief verwacht menig constructeur dat bijvoorbeeld de huls van een lucifersdoosje met de vingers aan beide einden door een wringend koppel belast (D.D.P. 15b) een tamelijk torsiestijf profiel zal zijn. Een huls die echter 90° gedraaid is, zodanig dat de wringende koppels op de strijkvlakken worden uitgeoefend (D.D.P. 15c), beschouwen de meeste mensen terecht als zeer torsieslap.
In feite is er natuurlijk geen enkel verschil in belasting en is de huls in beide standen even slap! Torsiestijfheidsberekeningen zijn gebaseerd op de aanname dat vlakke doorsneden vlak blijven en niet van vorm veranderen. Het zonder meer vlak houden van zo’n kokerprofiel doorsnede is niet gemakkelijk; maar wanneer men twee doorsneden verhindert van vorm te veranderen is het doel bereikt: er moeten dus twee tussen- of eindschotten worden aangebracht. Dit is de aangewezen constructie voor koelkasten (waar men liever heeft dat de kast als één geheel voorover komt als men te zwaar op de openstaande deur leunt, dan dat de kast alleen aan de scharnierzijde kantelt, dus verwringt, waardoor het koelsysteem kan gaan lekken).
De dorpel of de koelunit-ruimte kan als kokerprofiel opgevat worden, de zijwanden fungeren als de eindvlakken. Ook bij archiefkasten en zelfs de deuren ervan, bij stalen bureaukasten en laden en in het algemeen bij alle plaatconstructies met een ‘open doos’ karakter kan men desgewenst een grote torsiestijfheid inbouwen door een (vaak reeds aanwezig) uit omgezette randen verkregen kokerprofiel in zijn eindvlakken te fixeren. (al was het maar door de diagonalen vast te leggen door vier lasjes op de hoekpunten). Het gebruikelijke kantoormeubilair lijkt in dezen niet altijd voldoende doordacht (zie ook D.D.P. 170).

b)

c)

38

de constructeur / oktober 1978 / nr. 10

4

A page from DDP (as published by the Dutch professional magazine Constructeur in 1978) describing the design of stiff yet lightweight constructions.

This description of mechanical design issues and ways of thinking in order to find good solutions was the beginning of “The Devil’s Picture Book” (*Des Duivels Prentenboek*, or DDP), the collection of pictures that Van der Hoek amassed with the goal being to promote good designs from a dynamics and positioning point of view. Each picture, with a unique DDP number, was accompanied by a description of the corresponding design problem, the defects in the (initial) design and the experience gained in solving them. The central idea was: perhaps there are only a discrete number of problem types in the construction of precision machines and it is always a challenge to recognise the relevant problem type(s).

Lightweight and high stiffness was the first topic in DDP (Figure 4); avoiding backlash the second. The collection was soon extended to other topics: elastic elements, degrees of freedom, manipulation and adjustment, friction and hysteresis, the use of friction, guiding belts and wires, and energy management. Van der Hoek considered these subjects to be representative of ‘cold mechanical engineering’ and to be decisive for accuracy in movement and positioning.

ARRANGING THE DEGREES OF FREEDOM

Imagine that you would like to build an offshore windfarm in the harsh environment of the North Sea. At some point, this requires the transportation of wind turbine components to the offshore installation site, where they are installed. If, for a moment, you forget the wind and wave impact at the offshore installation site, this sounds quite doable. In practice, however, these two factors have considerable influence on the installation procedure through causing delays in lifting operations. This calls for a motion-compensation mechanism. Its design was founded on Wim van der Hoek's design principles.

MARTIN KRISTELIJN

AUTHOR'S NOTE

Martin Kristelijn graduated cum laude from Eindhoven University of Technology, Eindhoven (NL), in March 2018, in the study Mechanical Engineering, specialising in Design Principles. Currently he works at Bosch Rexroth (Boxtel, NL, www.boschrexroth.com) as a mechanical design engineer and has several side activities related to mechanical design. He is the recipient of the Wim van der Hoek Award 2018.

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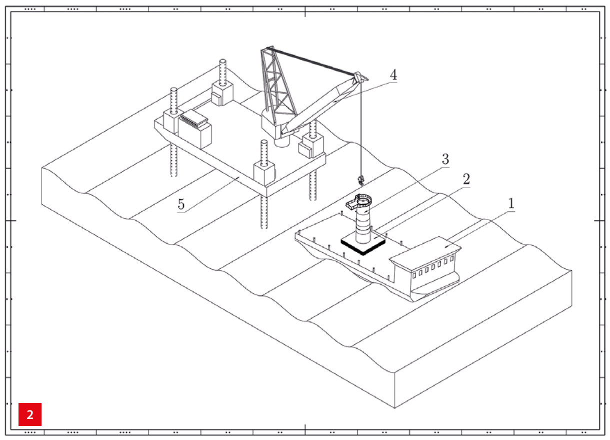
To minimise the influence of weather conditions, installing wind turbine components is commonly executed by a jack-up vessel, as shown in Figure 1, which can lift itself above the water line using its jack-up legs. In this jacked configuration, the deck crane (4) of the jack-up vessel, shown in Figure 2, stands stably on the sea floor and is therefore able to install the wind turbine components with high precision, minimally influenced by wind and waves. To streamline the installation sequence, the jack-up vessel is constantly fed with wind turbine components from a supply vessel (1).

1

Offshore wind turbine installed by a jack-up vessel. (Source: Siemens [1])

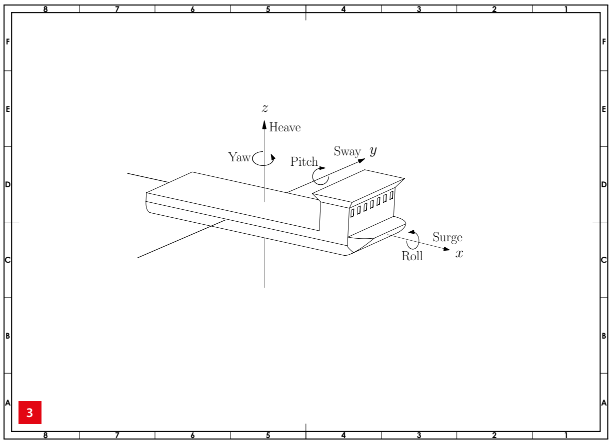


2

Overview of installation configuration.
(1) Supply vessel
(2) Platform
(3) Payload
(4) Deck crane
(5) Jack-up

The supply vessel has optimised sailing properties such as speed and manoeuvrability, which are convenient for long-distance transits and for positioning the floating supply vessel alongside the stationary jack-up vessel. The manoeuvrability of the supply vessel is provided by its dynamic positioning system, consisting of one thruster at each corner of the vessel's hull, which combined prescribe the horizontal motions of the vessel, i.e. surge, sway and yaw, as indicated in Figure 3.

However, the remaining wave-induced vessel motions, i.e. heave, roll and pitch, are uncontrolled vessel motions. When lifting payload (3) from the moving supply vessel, its uncontrolled heave, roll and pitch motions cause varying tension on the lifting cables that could damage the stationary jack-up crane and its lifting equipment; an example is given in this video [V1].



Degrees of freedom (DoFs) of the supply vessel.

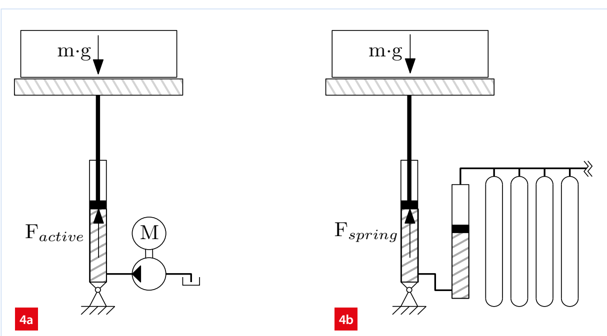
Placing the payload onto a motion-compensated platform (2) solves this challenge. Therefore, this article will describe the design of a motion-compensation mechanism that decouples the wave-induced vessel motions from its payload to facilitate safe offshore load transfer.

Specifications

The following specifications have been established in collaboration with Bosch Rexroth. The motion-compensation mechanism has to support a payload, positioned on a platform, with a maximum mass of 1,000 metric tonnes while compensating for motion in three degrees of freedom (DoFs), namely vessel heave, roll and pitch. The payload has to be offloaded with a rate in excess of 5 metric tonnes per second for a heave stroke of 3 m.

Passive heave compensation

Vessel heave motions can be compensated for by placing a vertically orientated hydraulic cylinder between the vessel's hull and the payload platform (see Figure 4a). The hydraulic cylinder is actuated to retract during upwards heave and to extend during downwards heave of the vessel. The payload therefore maintains its vertical position. The cylinder actuation is achieved using a hydraulic pump, powered by a diesel generator. To support a payload of 1,000 metric tonnes over a heave stroke of 3 m, however, several megawatts of peak power are required.



Heave compensation of the platform using a hydraulic cylinder.
(a) Actuated by an active hydraulic pump.
(b) Actuated by a passive gas spring.

A more energy-efficient solution is passive heave compensation. Instead of actively actuating the hydraulic cylinder over the vessel's heave stroke, the cylinder is connected to a large gas volume (see Figure 4b). Connecting a hydraulic cylinder to a gas volume yields the behaviour of a gas spring. Therefore, little active power is required to only compensate for the effect of the pressure-volume curve of the gas spring as induced by the volume variation of the hydraulic cylinder over the heave stroke.

The force of the gas spring F_{spring} is in balance with the combined weight of the payload $m{\cdot}g$, the platform and the proposed mechanism. Load transfer off or onto the platform causes an imbalance between the gas spring force and the weight it has to support. This leads to the hydraulic cylinder being extended uncontrollably by the pressurised gas and the platform potentially hitting the payload. Prevention can be managed by actively countering the gas spring force, again using a hydraulic pump driven by a diesel generator. This leads us back to the required several megawatts of peak power.

Load transfer mechanism

The imbalance between the gas spring force and the weight it has to support is prevented by introducing a lever between the platform and the gas spring. During offloading, the lever ratio increases gradually, after which the gas spring force is finally countered solely by the combined weight of the platform and the mechanism. Vice versa, during the loading of the payload onto the platform, the lever ratio reduces gradually such that the gas spring force remains balanced by the combined weight of the payload, the platform and the mechanism.

Figure 5a shows a payload with weight $m{\cdot}g$ on platform P_1, which is supported by mechanism I. The platform is rigidly connected to linkage GF, acting as a lever. Joints F and A are rigidly connected to the vessel and are therefore referred to as vessel ground joints. Linkage GF is vertically supported at joint C_0 by the gas spring's hydraulic cylinder B_1, whereas vessel ground joint A connects cylinder B_1 to the vessel. The cylinder supports linkage GF at half its length in joint C_0, giving it a lever ratio of 1:2, such that a payload mass of 1,000 tonnes / 2 = 500 tonnes is supported by the same gas spring as shown in Figure 4b, where it is supporting 1,000 tonnes. By translating joint C_0 over linkage GF, the lever ratio alters to perform load transfer.

During heave motion of the vessel, joints A and F move upwards, which requires the retraction of cylinder B_1 to maintain a stationary platform position. The resulting