60 Symposia on Inertial Sensors and Systems: A Remarkable Series in the Course of Time

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Abstract

The year 2023 marks the 60th symposium "*Inertial Sensors and Systems*" (ISS) of the German Institute of Navigation (DGON). Having been originally founded as a national working group for presenting and discussing current research topics and typical applications of gyro technology, this series of annual conferences quickly obtained international interest and became a well-known forum for scientists, manufacturers, and users. Coincidentally, an enormous evolution of gyro technology and inertial systems took place during the last decades. This development effected a great enhancement of the usability, applicability, and reliability of inertial technology that, if asked, probably would have been considered impossible by the founding fathers of the symposia. Nevertheless, the conference series was able to cover all these changes and to constantly represent the state of the art of inertial sensors and systems. The paper outlines the history of the symposia and characterizes trends associated with the conference audience and with the technology presented.

1. Introduction

Science and engineering of the 20th and 21st century is characterized by a virtually exponential, so far unknown growth of research findings and technical developments. Correspondingly, the number of special scientific fields, of relevant publications and individual conferences, and of available commercial products increased enormously. Furthermore, this situation is related to an accelerated, permanent change of scientific and technical subjects. Like the science itself, they show – on a shorter time scale – an individual exponential growth at the beginning, which is followed by a phase of saturation leading finally, e.g., to a constant importance or to a vanishing of the subject (in Section 3 this can be seen with different gyroscope types) [1]. Not perishing in such a lively environment and keeping track of the current developments in a specialized area is a complex and difficult task.

Against this background, it is indeed remarkable that the conference series "Inertial Sensors and Systems" of the German Institute of Navigation (DGON) can celebrate its 60th meeting this year. Obviously, the DGON symposia were able to comply with the challenges of strongly changing circumstances during the remarkably long period of up to now nearly six decades while contributing significantly to the art of inertial technology. The following paper on the history and development of the symposia appreciates this accomplishment.

To firstly understand the intention that led to establishing the conference series, it is helpful to repeat in extracts the (translated) address of Gerhard Zwiebler, former president of the German Hydrographic Institute (DHI), when he opened the first symposium in Hamburg on

June 1, 1965 [2]: "*The purpose and objective […] should be firstly to inform about the state of the art of navigation procedures and devices based on gyros, namely starting with the civil maritime transport. […] Therefore, we have at the beginning the gyrocompass in the sense of a north indicator. Subsequently, we would like to extend our efforts to the horizontal platform and the inertial navigation, also in the context of aerospace. […] Likewise, the usage of gyro devices and procedures shall be addressed on land, on land in the sense of surveying, and finally also in the sense of surveying below ground. Here, it will be necessary to address open questions and problems both by [basic] science and research as well as [application-related] investigations.*" These statements mirror that there was a substantial backlog on inertial technology in Germany in the middle of the 1960s – a typical circumstance of the post-war period – while maritime shipping companies, airlines, the army, and the mining industry in Germany strived for using modern gyro instruments again. Therefore, the conference series initially intended to bring together the users of gyro technology with scientists and manufacturers for a systematic professional exchange, which can be structured as follows.

- Inform about the state of the art of
  - gyro devices and systems,
  - inertial navigation devices and systems,
  - navigation methods based on this technology.
- Consider applications from
  - ships,
  - aerospace vehicles,
  - land vehicles,
  - surveying.
- Bring together experts from
  - basic science,
  - manufacturers,
  - commercial and governmental applications.

In principle, this structure applies until today. This is especially remarkable because it has never been written down like a charter and although the technological background and the dissemination of inertial sensors and systems have changed enormously: First, spinning mass gyroscopes and classical mechanical platforms were in the focus of the symposia for many years. They were followed gradually by optical gyroscopes and strapdown platforms. Meanwhile, inertial sensors of the MEMS (Micro-Electro-Mechanical Systems) technology, integrated navigation systems and low-cost applications constitute a significant part of the annual symposia.

To get a closer look at how the conference series developed within these changing circumstances and technological trends, the following sections outline its organizational development, characterize its audience, and look at the inertial sensor technology covered. Concurrently, the paper continues an article of Wagner and Perlmutter from 2015 [2] by summarizing and updating its content and considering especially the last 20 years of the symposia.

2. Origin and Organizational Development of the Symposia

The root of classical gyro technology is the invention of the gyro with cardanic suspension by J.G.F. Bohnenberger, Astronomer at the University in Tübingen, Germany, in 1810 and the following work of J.B.L. Foucault on gyroscopes in Paris four decades later [3]. While subsequently the theory of the gyro was a classic area of physics already during the 19th century, the first successful technical applications did not follow until the beginning of the 20th century, when pioneers like E. Sperry, H. Anschütz-Kaempfe, and M. Schuler accomplished the early usable gyroscopes for navigation. In the following decades, Germany became the world's leading country in gyro technology – a position, which got lost at the end of the Second World War.

A new beginning in gyro technology occurred in West Germany around 1960. Partially supported by enterprises from US, traditional companies like Anschütz (Kiel), C. Plath (Hamburg; today part of Litef), and Bodenseewerk (Überlingen; offshoot of the Askania-Werke, today part of the Diehl group) had been reestablished, and the new German-US companies Litef (Freiburg) and Teldix (Heidelberg; today part of Collins Aerospace) arose. In addition, former gyro specialists had returned from Russia and the USA to Germany. Among these persons was Kurt Magnus, who was a former PhD student of M. Schuler and who had become professor of mechanics at the University of Stuttgart in 1958 [4], [5].

The new German activities in gyro technology required a professional forum for networking and for exchanging new findings in research and development. Based on the initiative of K. Magnus, G. Zwiebler, and other individuals, the German Institute of Navigation (DGON) constituted therefore a working group called “Fachausschuss 8” (Technical Committee 8, FA 8) in 1965. This group of experts had the task of setting up such a forum in the manner described by G. Zwiebler above (and had also to deal with gyroscope standardization [6]). During the following years, the committee held eight plenary sessions on inertial technology. These meetings were so successful that they became internationally known and continued despite the DGON's decision to close FA 8 in 1971.

To structure the further development of the symposia, a division into several phases is helpful. Most of the details of these periods derive from documents of the Archive of the University of Stuttgart [7] and from the conference proceedings. This applies also to the Annex, which lists the chronological sequence of the conference series as well as all former and current persons being responsible for the scientific arrangement of the symposia.

1) Initial phase (1965 to 1971)

The first period comprises the eight plenary sessions of the FA 8, as mentioned, and an additional conference with the new name *"Symposium über Kreiseltechnik"* (Symposium about Gyro Technology) in 1971. The symposia were organized by the DGON, were alternately hosted by industrial companies und research institutions, and were combined with factory and laboratory tours. The presentations were initially invited and held under one special theme like "gyrocompass developments" or "inertial platforms". The proceedings consisted of sets of unbounded handouts; selected papers were afterwards additionally published in the DGON journal "Ortung und Navigation". Furthermore, a rhythm of annual conferences turned out to be appropriate.

2) Consolidation phase (1972 to 1978)

The next period had to face several substantial challenges: The external framework of the FA 8 was no longer available, the DGON gradually gave up the conference management, the business of gyro technology became increasingly international, and optics as well as electronics became equivalent disciplines besides mechanics in the area of inertial systems.

At the beginning of this phase, Helmut Sorg, a former PhD student of K. Magnus at the University of Stuttgart, took the conference chair and initiated significant organizational changes, which gradually became effective and which characterize the symposia until today:

(i) Preparing the symposia by the public "Call for Papers",
(ii) establishing a scientific program committee of experts for paper reviews etc.,
(iii) admitting English papers,
(iv) publishing regular printed proceedings,
(v) establishing September as the regular time for holding the symposia,
(vi) changing the conference title to *"Symposium Gyro Technology"*.

Finally, English became the only conference language - a point that illustrates that a well-recognized international symposium had gradually emerged during the first and second phase.

3) A long phase in Stuttgart (1979 to 2006)

The transition to the third phase and the last part of the symposium reorganization consisted in the takeover of the main conference management by H. Sorg and his team at the Institute A of Mechanics at the University of Stuttgart, which simultaneously became the symposium venue for the whole period. The result of all these measures was a remarkable organizational steadiness of 28 years (until the retirement of H. Sorg), which in retrospect seems the necessary condition for covering the huge technological changes being outlined above. The most considerable single event of this time, however, was the end of the Cold War, which opened the symposia also to attendees from Eastern Europe.

4) The modernization phase in Karlsruhe (2007 to 2017)

The end of the third period entailed a generation change and was therefore the right time to update the organization of the symposia. That the latter, vital task succeeded is to the special credit of Gert Trommer, who took the conference chair in 2007 and gave the conference series a new home at the Institute of Systems Optimization at the University of Karlsruhe (now the KIT). Maintaining the feeling of steadiness of the third segment, he and his team held the meetings with a lot of dedication, increased the international visibility of the events, updated the symposium management, and changed the proceedings to an electronic format being published at *ieeexplore.ieee.org* now. To better reflect the character of inertial technology, as it had been developed in the past decades, the conference title was additionally revised to *"Inertial Sensors and Systems"* in 2011.

5) The current phase in Braunschweig (since 2018)

The retirement of G. Trommer required again to transfer the symposia to a new place, the Institute of Flight Guidance at the Technical University of Braunschweig with Peter Hecker as conference chair. Soon after the changeover of the conference management and the strengthening of the program committee by international members, the meetings had to face the Corona pandemic. This was a break never seen before in the history of the symposia. P. Hecker and his team did a remarkable job in organizing web conferences in 2020 and 2021. Meanwhile, the conference series is in the post-pandemic phase and, looking at the statistics in the following section, will hopefully completely recover during the next time.

3. The Audience of the Symposia

Based on the attendance lists, which survived for most of the symposia [7], noteworthy details about the conference audience can be identified. Fig. 1 and Fig. 2 show the development of the number of participants and the number of countries the participants came

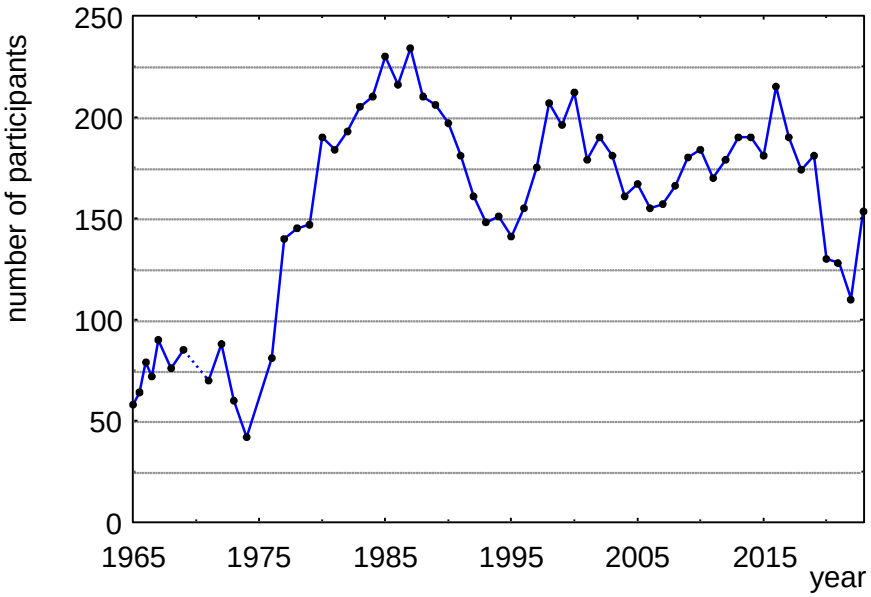

Figure 1. Number of symposium participants.

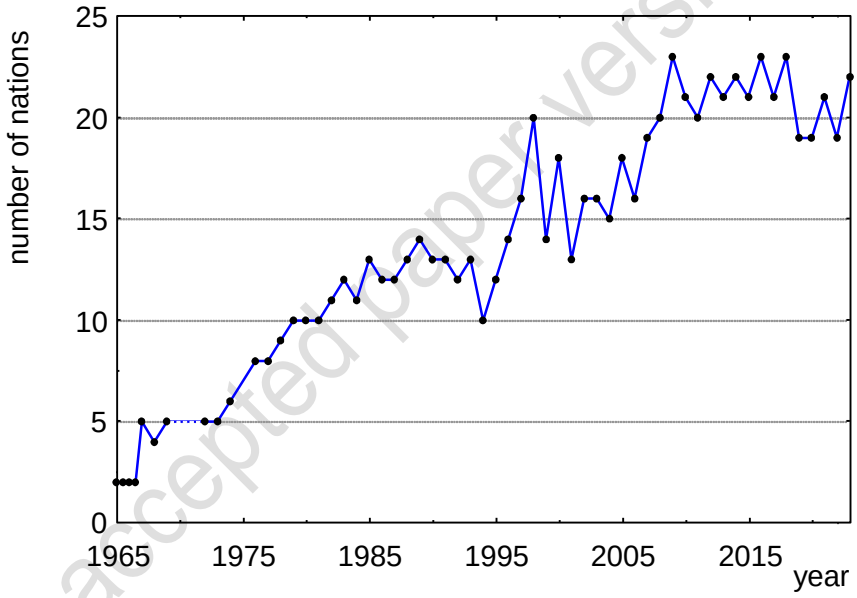

Figure 2. Number of participating nations.

from. During the initial phase, the symposia had an average of about 75 attendees from two to five nations. The crisis of conferences at the beginning of the second phase is visible from the decreasing number of participants, while the number of countries remained nevertheless around five. Then, the symposium reorganization effected a strong and continuous rebound, which continued in the third phase to the end of the Cold War and reached more than 200 attendees per meeting. Some years of reduced interest followed until the number of attendees recovered and the number of nations started to rise again. The generation change at the end of the third phase (and perhaps the financial crisis of the dot-com bubble) was connected with a new decline in the number of participants. A recovering followed during

the modernization of the symposia again, while the number of countries reached a saturation level of about 22. Finally, Fig. 1 and 2 reflect the adverse solid effect of the coronavirus pandemic for the years 2020 to 2022 and indicate a recovering in 2023.

To facilitate an assessment of the development the conference may take in the near future, Fig. 3 and 4 give an insight in the composition of the audience during the last 20 years. Fig. 3 illustrates that the conference series was always a European one (cf. also [2]), but the share of participants from North America and the Far East shows a continuous rise from nearly zero to about 10%. (For better visibility of the "Non-European curves", these are repeated in the lower part of the diagram.) The part of the remaining nations has a nearly constant level of about 5% with Israel representing the most significant country.

It should be added that besides Germany especially France and then Scandinavia, the UK, Russia, Switzerland, Italy, and Ukraine made up the European part. The share of North America is mainly attributed to the USA. Although this country once had a share of more than 10% during the 1970s and 1980s [2], its part fell afterward and nearly vanished during

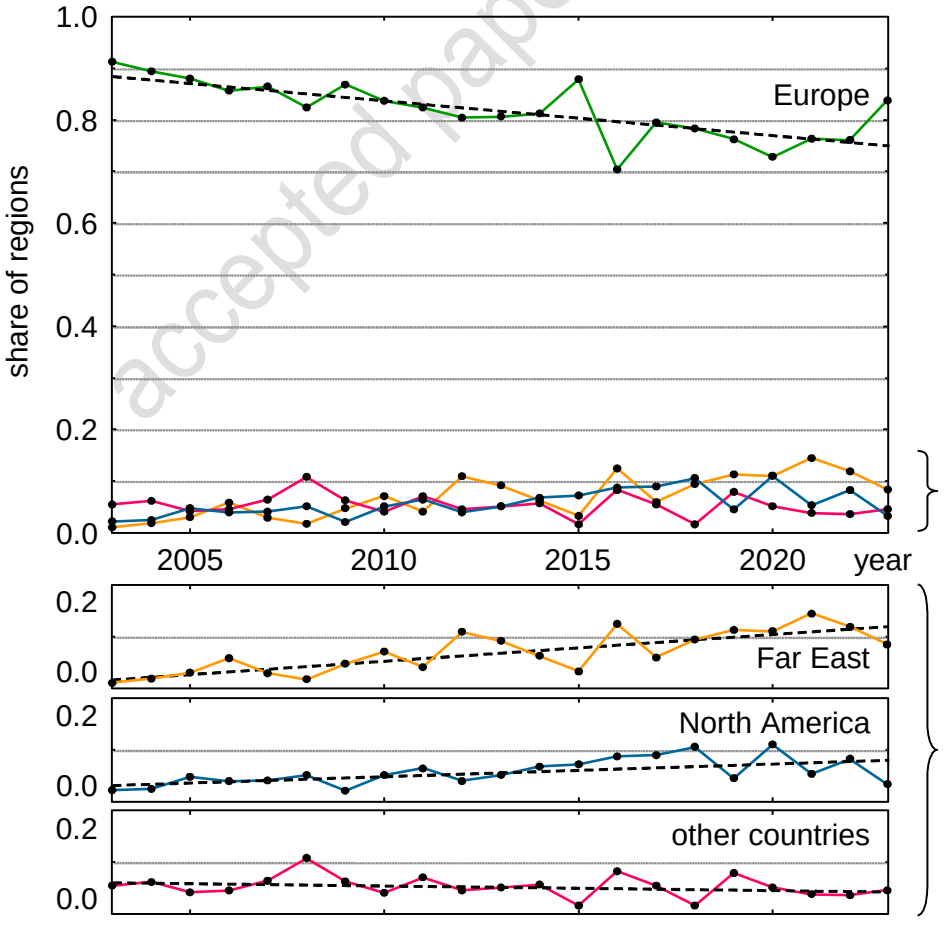

Figure 3. Share of the regions the participants came from with trend lines for the last 20 years.

the generation change at the end of the third conference phase while considerably recovering again during the last two decades.

Fig. 4 illustrates the professional background of the attendees. Traditionally, the group of participants from manufacturers of sensors and systems as well as from engineering firms ("commercial group") is biggest one [2]. Attendees from research institutions like universities follow with a remarkable unequal distribution: Most of these individuals came from Germany, Eastern Europe, and China, while the participants from the other countries have mainly to be assigned to the commercial group. The smallest part of the attendees consists of representatives from users of inertial technology like airlines and public authorities. Its significance is meanwhile relatively small although the DGON initially identified this group as a primary motive for establishing the conference series.

An interesting exchange of shares is observable between the commercial and the research group. During the generation change at the end of the third conference phase, the researchers had a proportion of about one-third, which was relatively high for the previous conference series [2] and which lowered again to about 20% during the time in Karlsruhe. In the meantime, this share rose again to a higher level and may indicate that industry suffered more from the Corona pandemic than research institutions.

A final but important remark about the audience of the conference series should be made to appreciate the special loyal participants of the meetings. While browsing through the numerous attendance lists, one can notice many individuals who constantly registered during long periods of 20 years and more (typically until their retirement or longer). Some of these per-

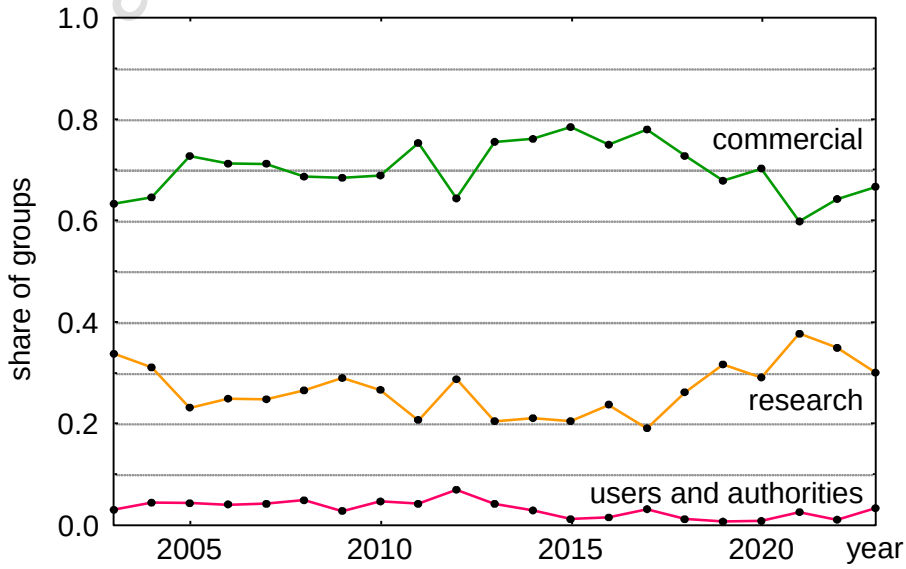

Figure 4. Share of the professional environments of the participants for the last 20 years.

sons presented several times a paper, some were session chairmen or members of the program committee, others managed exhibition booths, and many used the symposia simply for professional development and networking. Together with the generosity of the conference chairmen, who – as a matter of course – provided the resources of their institute for holding the symposia, the regular attendance of this group of participants formed the basis of the success of the symposia during all decades – in organizational as well as in content-related terms – and gave the annual meetings a family atmosphere.

4. The Technical Content of the Symposia

To support a systematic and easy understanding of developments, changes, and trends of the inertial technology covered by the conference series, Wagner and Perlmutter reviewed already the proceedings of all symposia published until 2014 [2]. Due to the rapid industrial progress in this area, it seems appropriate to update the former statistics now and to summarize this previous paper while having a closer look at the new conference papers published in the meantime. Beforehand, some remarks about the conference proceedings themselves should be made.

4.1. The Proceedings Volumes

During the last years, the author could collect a complete set of the conference proceedings, which were distributed over different libraries. Some of the old volumes were obviously the last existing copies. Due to this critical circumstance and to establish a digital library on inertial technology, he scanned all volumes from 1965 to 2006, which existed only as paper copies, and converted them into searchable pdf-files by using the professional digitization software ABBYY FineReader®. By combining these files with the digitally prepared conference proceedings of the organizing committees in Karlsruhe and Braunschweig, a unique, still growing technical library could be compiled. Its quantity of all papers will pass the number of 1,000 this year. To this, Fig. 5 shows the annual number of papers (incl. posters) presented during the symposia. On average, steady growth is visible but the effects of the end of the Cold War and the Corona pandemic are also noticeable.

In principle, the content of the proceedings volumes mirrors the assessment of the program committee and the conference chairs about the importance of new ideas, technologies, and applications of inertial sensors and systems. Throughout the years, this group of persons was composed of experienced engineers and physicists from several industrial companies and research institutions and consisted of 4 to 15 members having been selected by the conference organizers. On this basis, the invited sessions of the initial symposia addressed

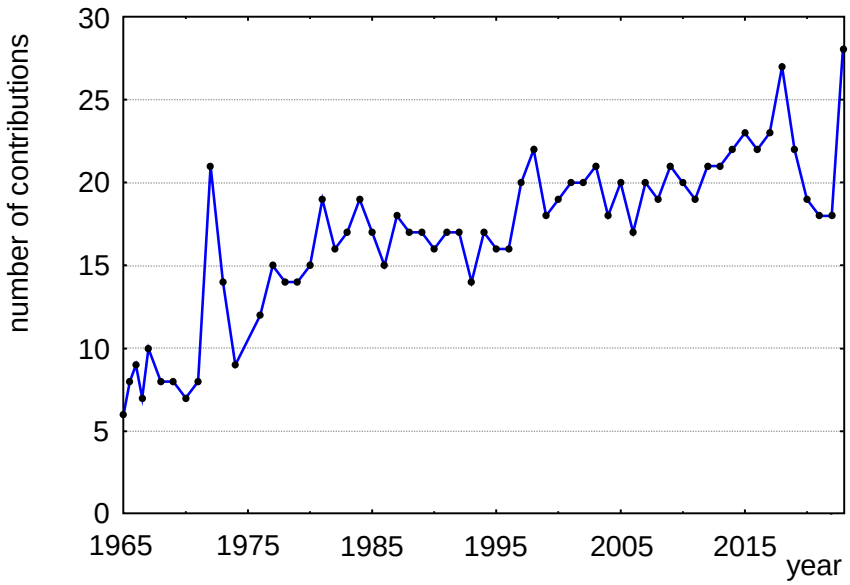

Figure 5. Number of presented papers and posters.

central, current subjects, and the following calls for papers supported additionally the topicality and balance of all contributions in the proceedings volumes. Therefore, the conference papers as a whole should represent the factual trends in inertial technology since 1965.

All papers having been published since 2014 are accessible through the internet portal *ieeexplore.ieee.org*. All earlier proceedings volumes are available at the library of the University of Stuttgart. Other university libraries in Germany and the USA have also proceedings of a significant number of years between 1965 to 2013 at hand. Due to copyright matters, public access to the digital volumes from 1965 to 2013 is not yet regulated, but the complete digital sets are already prepared. The Annex contains an overview on all conference proceedings and lists also the dedications of single volumes honoring contributors and contributions to gyro technology.

4.2. Technological Trends of Gyroscopes

As mentioned, the proceedings volumes mirror the research and development efforts in the field of inertial sensors and systems since the 1960s. They reflect what specialists have done and are doing to improve and apply this kind of technology. Thus, the volumes constitute a targeted sample that can be interpreted, e.g., as early indicators of products that will later appear on the market or as lines of technological development. Accordingly, they will be used statistically in the following to quantify the technological trends in inertial sensors and systems during the last decades.

Fig. 6 displays the annual paper shares of the main types of gyroscopes discussed throughout the years. To prepare this statistic, the papers of every year were reviewed and then

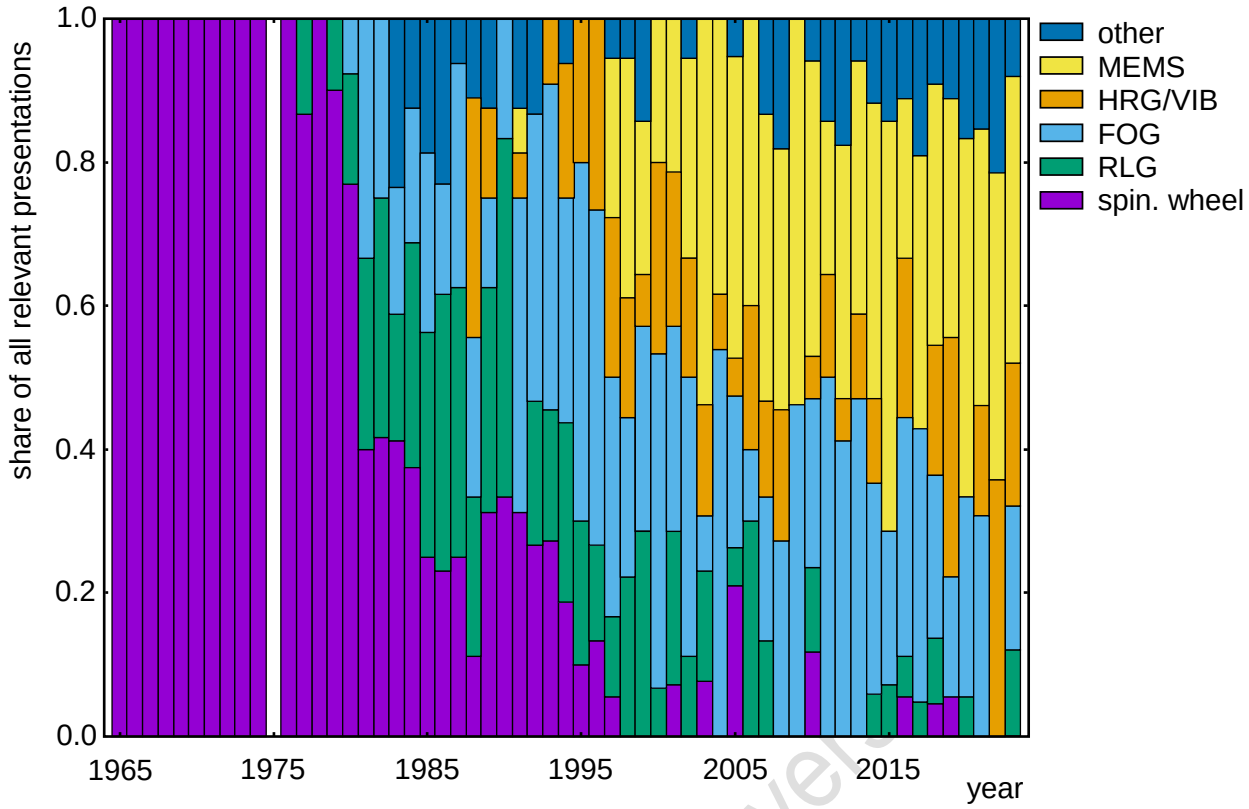

Figure 6. Different types of gyroscopes as presented from 1965 through 2022.

assigned to one gyroscope type [2]. If, e.g., a contribution discussed the layout, a component, the fabrication, or the application of a MEMS inertial measurement unit (IMU), it was counted among the group of MEMS papers. An exception is contributions reviewing equally several specific gyroscope types or addressing non-inertial technology (like aiding by GNSS) etc.; they were not considered for the statistic.

The diagram illustrates that the classical gyros with spinning wheels clearly dominated the conference series for nearly two decades. The emergence of the Ring Laser Gyro (RLG) and the Fiber-Optic Gyro (FOG) affected this position, and a few years later optical gyroscopes prevailed during the symposia for many years. During the 1990s, vibration type sensors (VIB) like the Hemispherical Resonator Gyroscope (HRG) and MEMS type gyroscopes took root and now share the biggest part of the presentations. While FOGs also form a still significant sensor type, the importance of classical gyros and RLGs is meanwhile limited to particular cases.

For a more detailed insight into these technological changes, Fig. 7 shows additionally the separated, individual paper shares for the six groups of Fig. 6. Where appropriate, these diagrams also contain (dashed) trend lines. For the classical gyros with spinning masses and the MEMS gyroscopes, the logistic equation

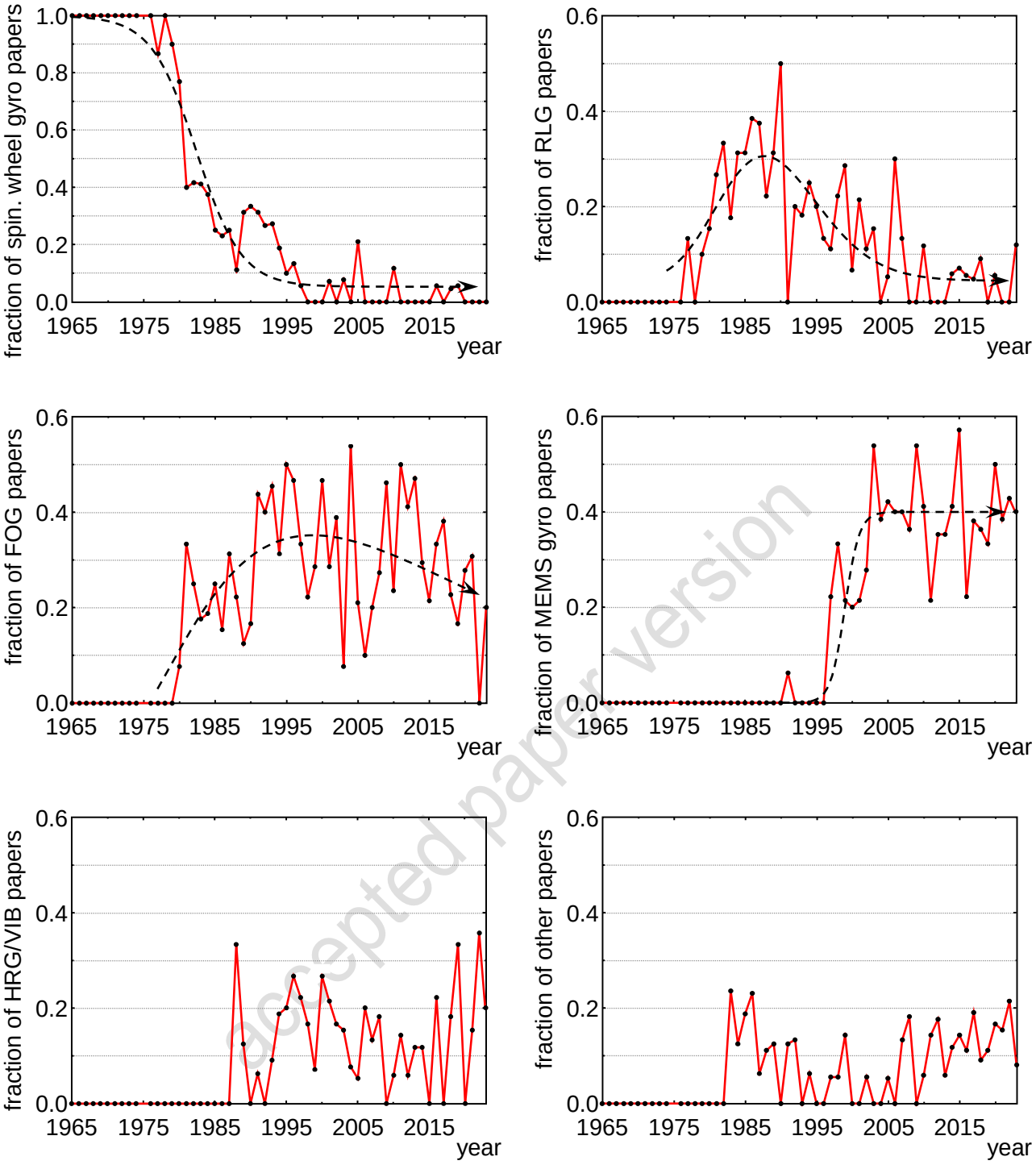

Figure 7. Paper fractions of different gyroscope types as presented from 1965 through 2022.

$$f_g(t) = \frac{c_1}{1+\exp(-c_2(t-c_3))} \quad \text{and} \quad f_d(t) = c_0 - \frac{c_1}{1+\exp(-c_2(t-c_3))}, \tag{1}$$

being a common function f for modeling a population growth g or decline d with time t [1], proved to be appropriate as a trend line. Regression calculation was used to determine the numerical values of the constants c_1 to c_3. For the trendline of the RLG and the FOG, the alternative log-normal distribution

$$f_{gd}(t) = \frac{c_1}{t} \exp\left(-\frac{(\ln(t) - c_2)^2}{c_3} \right) \tag{2}$$

for modelling a combined population growth and decline *gd* [8] proved suitable. The diagrams for the HRG/VIB group and the group of other sensor types have no trendlines as both curves show a sudden initial step during the 1980s and, since then, vary strongly around a mean value of about 0.1 without an apparent tendency.

The upper left diagram of Fig. 7 clearly shows the sharp loss of importance of the classical gyros during the 1980s while the RLG became (less pronounced) the most significant sensor type. Only one decade later, the crowding-out process repeated, and the FOG took the place of the most relevant gyroscope. The FOG importance still continues, but the MEMS gyroscopes, which paved the way to smaller and more cost-effective IMUs as well as to new applications, replaced the FOG as the primary sensor principle around the year 2005. It is remarkable that the growth phase of the MEMS sensors was similarly rapid like the decline of the classical gyros. Meanwhile, this new sensor type has reached obviously a saturation phase. The future will show if a technological leap will lead to a further growth of the MEMS importance [1], to a renaissance of FOG instead of its currently decreasing tendency, or, e.g., to an establishment of NMRGs (Nuclear Magnetic Resonance Gyroscopes).

4.3. Survey of the Proceedings Volumes

To extend the analysis of subsection 4.2 to navigation systems, sensor components, and applications, the existing overview from 2015 [2] on the proceedings volumes is summarized by using a list of topics. This is done decade by decade until 2002. Then, a more detailed view follows for the remaining, the last 20 years.

The 1960s

- Gimballed platforms,
- north seeking gyros: gyrocompasses and gyro theodolites mainly for mine surveying,
- accuracy requirements:
  - 0.001 deg/h for ships,
  - 0.01 deg/h for aircraft,
  - 0.1 deg/h for rockets,
- gas and ball bearings for spinning wheel gyros,
- first reflections about vibrating gyroscopes,
- standardizing of nomenclature and testing of gyros.

The 1970s

- First strapdown platforms,
- platform alignment,
- first Kalman filters,
- dynamically tuned gyros (DTG, favored gyro type of the 1970s),
- north seeking gyros (now also for aircraft),
- first RLGs,
- bearings for spinning wheel gyros,
- first low-cost inertial grade accelerometer,
- reduction of system weight and power consumption by a factor of 2 to 3,
- doubling of the Mean Time Between Failure (MTBF) from 50 h to 100 h (typical values).

The 1980s

- First FOGs (stimulated by the success of the RLGs),
- competition between spinning wheel gyros, RLGs, and FOGs,
- biasing mechanisms and other improvements of RLGs (favored gyro type of the 1980s),
- integrated optics for overcoming the high price of optical fibers,
- optical gyroscopes for very high precision (i.e. 10^{-10}-fold of the earth rate),
- first mention of NMRGs,
- Kalman filter and software aspects for inertial navigation systems:
  development and verification,
  flight safety critical equipment,
- sensor and system redundancy,
- introduction of satellite navigation (GPS) for aiding inertial systems.

The 1990s and early 2000s

- Bountiful number of different gyroscope designs,
- various improvements of FOGs (favored gyro type of this era),
- space applications of FOGs,
- first vibrating gyroscopes (tuning fork class, hemispherical resonator),
- first MEMS designs for inertial sensors,
  indicating farsightedly the high potential for IMU miniaturization and cost reduction,
- first applications for low-cost IMUs (automated vehicles),
- fault tolerant system design with long MTBF,

- integration of inertial navigation systems and satellite navigation,
- standardizing of nomenclature and testing methods of inertial sensors.

The last 20 years

While browsing through the proceedings volumes since 2003, the first impression is a clear thematic expansion (having its roots already in the 1990s). The author attributes three reasons for this effect. The first is a variety of gyroscopes and aiding technologies never seen before, which offers a wide range of different accuracy levels as well as of small and/or cost-effective system components. This enables, as the second reason, many applications in navigation, control, positioning, etc. that were previously excluded from inertial technology. The third reason consists in numerous new methods of designing, analyzing, and testing inertial sensors and systems to a level of detail also never have seen before. Against this background, not a chronological but thematic breakdown is chosen for the proceedings volumes:

MEMS sensors have been the favored gyro type since the middle of the 2000s. In the proceedings volumes of every year, one can find many papers on designing, analyzing, manufacturing, signal processing, and increasing the performance (e.g. by self-calibrating) of this type of gyroscopes and – as a gain in importance – accelerometers. Initially, single sensors had the majority of the presentations. Meanwhile, complete IMUs are standard (and led to additional price reductions for inertial sensors). Furthermore, classical and new utilizations were constantly demonstrated: firstly, robotics, stabilization, and automotive applications, then railways, biomechanics, mapping, north finding, and smartphones. Therefore, it was consequent that several surveys on the market and applications of MEMS inertial sensors appeared during the 2010s. Finally, occasional contributions on MEMS calibration, sensor blending, and big data error statistics have to be mentioned for the 2010s, too.

FOGs are still the second most important sensor type and showed a similarly rich range of papers. As for the MEMS gyroscopes, increasing the sensor performance was the main topic and addressed on one side components like light sources, depolarizers, control and signal processing procedures, as well as – particularly frequent since the 2010s – the fibers, while on the other side investigations about ambient conditions like vibrations, radiation, and heat, as well as miniaturization were also presented repeatedly. Space applications had a high importance but also utilizations for north finding, robotics, underwater vehicles (with an INS accuracy up to 1 nm/month), railways, structural monitoring of buildings, and precise inclinometers have to be mentioned.

Other vibration-type gyroscopes, mainly the HRG (as a sensor of especially high reliability) and tuning fork species, were regularly but less frequently addressed. The main emphasis was on research topics like design, structural analysis, control, and manufacturing. Similar to the FOGs, typical applications were space and land vehicles as well as north finding.

RLGs and spinning wheel gyros rarely appeared anymore with papers covering specific topics like large and very accurate gyroscopes ($1 \cdot 10^{-12}$ rad/s), precise inclinometers, solid state RLGs, and rotor bearings. These contributions were a reminder that classic gyroscopes still have their particular strengths for demanding applications and that they can "survive" in niches with a wealth of experience for a specific type of gyro.

Atomic physics-based gyroscopes like the NMRG started to show up during the symposia in the middle of the 2010s. They are still mainly in the state of basic research, and marketable products are rare to date.

Strapdown systems, including *Attitude and Heading Reference Systems* (AHRS) were addressed permanently during the last 20 years. Here, integrated systems with a variety of aiding techniques – firstly satellite navigation receivers with one or multiple antennas but (e.g. for GPS-denied environments) also radar and lidar, magnetometers, terrain-based techniques, and cameras – formed the biggest focus. Further system-orientated aspects were alignment and transfer alignment, numerics of attitude calculation, system integration concepts, reliability, and integrity. Among the applications, pedestrian and indoor navigation established a considerable new group at the end of the 2000s. Nevertheless, the importance of vehicle applications grew furthermore as (besides the traditional automotive use) underwater vehicles and inland vessels, Unmanned Aerial Vehicles (UAVs), and swarm navigation showed up as new topics during the 2010s.

Other technical topics with a more general perspective and without relation to one specific gyro type are also part of the thematic variety of the last 20 years. From the methodological point of view, simulation and testing techniques were repeatedly presented, while other papers addressed aspects of redundancy, IMU design, requirements, certification and, error budgets. In addition to the applications already mentioned above, gravimetry, surveying of boreholes, measuring structural deformation, and again north finding – maybe the supreme discipline of gyroscopy – were addressed repeatedly.

Historical papers are the last group of contributions. They continue a tradition of the symposia that keeps the memory of the roots of gyro technology alive. Their presentations honored on one side inventions and discoveries like the Machine of Bohnenberger, the Sagnac effect, the traditional and the orbital gyrocompass, and on the other side important personalities like K. Magnus and J. Gievers. Other contributions addressed museum aspects, the advance of standards, or the development of product lines.

5. The Years to Come

Predicting the reputation and the technical content of future symposia is naturally an uncertain task. From the 1970s to the 1990s, the ISS meetings had an exceptional position, which reached clearly beyond Europe [9]. Meanwhile, other conferences with similar profiles exist as well as application-oriented congresses, which pragmatically treat inertial systems as one technology among others. This fact mirrors in particular the enormously increased popularity of inertial technology but did not markedly affect the reception of the ISS symposia up to now. Nevertheless, future efforts to maintain the position of the conference series are vital.

Forecasting the technological development of inertial sensors and systems is even more difficult. Possibly, MEMS sensors will more and more advance into the accuracy range of the FOGs, which for their part will perhaps fully replace the RLGs and spinning wheel gyros. A further question is if atomic physics-based gyroscopes will break the current accuracy limits. On the other hand, it seems likely that small inertial sensors will be present in even more aspects of work life, leisure, and medical monitoring. E.g., wearable body sensor networks with distributed IMUs being invisibly sewn in clothes appear feasible for individuals controlling vehicles or machines.

It is sure, however, that inertial technology has reached a very high performance and applicability that, if asked, probably would have been considered impossible by the founding fathers of the ISS conferences. Keeping that in mind, it will be interesting to see what the future will bring.

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Annex: Organizational and Historical Details

Table 1. Chronology of the conference series.

Year	Date	Local organizer, venue	Remarks
1965	June 1 - 2	DHI, Hamburg	1st meeting of the "DGON-Fachausschuss 8", until 1970, the proceedings were an appendix to the minutes of the meeting, 2 papers published additionally in the in the DGON journal *Ortung und Navigation* IV/65
	October 19 - 20	Univ. of Stuttgart	1 paper additionally in *Ortung und Navigation* IV/65
1966	March 29 - 30	Westfälische Berggewerk-schaftskasse, Bochum	1 paper additionally in *Ortung und Navigation* II/66
	October 3 - 4	Teldix, Heidelberg	1 paper additionally in *Ortung und Navigation* I/67
1967	April 18 - 19	Bodenseewerk, Überlingen	3 papers additionally in *Ortung und Navigation* III/67
1968	May 16 - 17	Litton, Freiburg	3 papers additionally in *Ortung und Navigation* III/68
1969	March 20	Techn. Univ. of Munich	3 papers additionally in *Ortung und Navigation* III/69
1970	February 19 - 20	Techn. Univ. of Clausthal-Zellerfeld	8th and formally last meeting of the "DGON-Fachausschuss 8"
1971	May 27 - 28	Anschütz, Kiel	Name changed to "Symposium über Kreiseltechnik", all papers published in *Ortung und Navigation* III/71
1972	April 12 - 14	Bodenseewerk, Überlingen	First papers in English, first regular proceedings, attendees from outside Europe
1973	April 25 - 27	Westfälische Berggewerk-schaftskasse, Bochum	10 papers published in *Ortung und Navigation* II/73 and IV/73, 4 papers were only available as handouts
1974	April 25 - 26	Teldix, Heidelberg	From now on, regular printed proceedings are published
1975	(Autumn)	(Litton, Freiburg)	Symposium was cancelled
1976	March 31 - April 1	Techn. Univ. of Braunschweig	
1977	September 28 - 29	Univ. of Stuttgart	From now on, all presentations are in English, September is now symposium time frame, Institute A for Mechanics, Univ. of Stuttgart, becomes co-organizer
1978	September 18 - 19	Westfälische Berggewerk-schaftskasse, Bochum	Probably first attendees from Asia
1979	September 25 - 26	Univ. of Stuttgart	Name changed to "Symposium Gyro Technology", English is now the only conference language, in commemoration of Johannes Gievers
1980	September 24 - 25	Univ. of Stuttgart	
1981	September 23 - 24	Univ. of Stuttgart	Institute A for Mechanics, Univ. of Stuttgart, becomes main organizer
1982	September 15 - 16	Univ. of Stuttgart	Dedication: 70th birthday of Kurt Magnus

1983	September 14 - 15	Univ. of Stuttgart	
1984	September 11 - 12	Univ. of Stuttgart	
1985	September 24 - 25	Univ. of Stuttgart	
1986	September 23 - 24	Univ. of Stuttgart	
1987	September 22 - 23	Univ. of Stuttgart	In commemoration of Charles Stark Draper
1988	September 20 - 21	Univ. of Stuttgart	
1989	September 19 - 20	Univ. of Stuttgart	
1990	September 25 - 26	Univ. of Stuttgart	In commemoration of Walter Wrigley
1991	September 24 - 25	Univ. of Stuttgart	First attendees from the former Warsaw Pact
1992	September 22 - 23	Univ. of Stuttgart	Increasing number of papers on civil applications of inertial systems
1993	September 21 - 22	Univ. of Stuttgart	Decreasing number of attendees with military background
1994	September 20 - 21	Univ. of Stuttgart	
1995	September 19 - 20	Univ. of Stuttgart	Dedication: Manfred Pütz and Rainer Sindlinger
1996	September 17 - 18	Univ. of Stuttgart	
1997	September 16 - 17	Univ. of Stuttgart	
1998	September 15 - 16	Univ. of Stuttgart	
1999	September 14 - 15	Univ. of Stuttgart	
2000	September 19 - 20	Univ. of Stuttgart	
2001	September 18 - 19	Univ. of Stuttgart	
2002	September 17 - 18	Univ. of Stuttgart	Dedication: 90th birthday of Kurt Magnus
2003	September 16 - 17	Univ. of Stuttgart	
2004	September 21 - 22	Univ. of Stuttgart	
2005	September 20 - 21	Univ. of Stuttgart	
2006	September 19 -20	Univ. of Stuttgart	
2007	September 18 - 19	Univ. of Karlsruhe	Institute of Systems Optimization, Univ. of Karlsruhe, becomes main organizer
2008	September 16 - 17	Univ. of Karlsruhe	
2009	September 22 - 23	Univ. of Karlsruhe	
2010	September 21 - 22	Karlsruhe Inst. of Techn.	Dedication: 200 years of gimbal mounted gyroscopes
2011	September 20 - 21	Karlsruhe Inst. of Techn.	Name changed to “Inertial Sensors and Systems”
2012	September 18 - 19	Karlsruhe Inst. of Techn.	Dedication: 100th birthday of Kurt Magnus
2013	September 17 - 18	Karlsruhe Inst. of Techn.	Dedication: 100 years of the Sagnac effect
2014	September 16 - 17	Karlsruhe Inst. of Techn.	From now on, the proceedings are published digitally at *ieeexplore.ieee.org*
2015	September 22 - 23	Karlsruhe Inst. of Techn.	Dedication: The symposium turns 50
2016	September 20 - 21	Karlsruhe Inst. of Techn.	
2017	September 19 - 20	Karlsruhe Inst. of Techn.	
2018	September 11 - 12	Techn. Univ. of Braunschweig	Institute of Flight Guidance, Technical University of Braunschweig, becomes main organizer

2019	September 10 - 11	Techn. Univ. of Braunschweig	Dedication: 85th birthday of Helmut Sorg
2020	September 15 - 16	Techn. Univ. of Braunschweig	Only web conference due to the Corona pandemic
2021	September 29 - 30	Techn. Univ. of Braunschweig	Only web conference due to the Corona pandemic
2022	September 13 - 14	Techn. Univ. of Braunschweig	
2023	October 24 - 25	Techn. Univ. of Braunschweig	60th symposium, exhibition of historical inertial sensors and systems

Table 2. Chair of the symposium, chair and members of the program committee.

Symposium chair		**Program committee chair**	
Gerhard Zwiebler	1965 - 1966		
Kurt Magnus	1966 - 1971	Manfred Pütz	1972 - 1995
Helmut W. Sorg	1972 - 2006	Walter Bernard	1996 - 2014
Gert F. Trommer	2007 - 2017	Steffen Zimmermann	since 2015
Peter Hecker	since 2018		

All other former and current members of the program committee		
Wilfried Auch	Thomas Löffler	Jörg Steinwand
Peter Christoph	Ulrich Mangold	Oleg Stepanov
Fabrice Delhaye	Fedor Matezky	Bernhard Stieler
Thomas Erler	Bertrand Morbieu	Karl Heinrich Stier
Eduard Fischel	Michael Perlmutter	Jörg Wagner
Wolfram Geiger	Kurt Schlichting	Detlev Wick
Ulrich Henke	Gerhard Schweitzer	Yuanxin Wu
Uwe Herberth	Andrei Shkel	
Edgar von Hinüber	Rainer Sindlinger	