2023 IEEE International Workshop on Metrology for Automotive (MetroAutomotive) | 979-8-3503-2187-6/23/$31.00 ©2023 IEEE | DOI: 10.1109/MetroAutomotive57488.2023.10219116

Challenges in designing measurement systems for Formula One cars

Przemysław WOJCIECHOWSKI
Faculty of Mechatronics, Armament and Aerospace
Military University of Technology
Warsaw, Poland
przemyslaw.wojciechowski@wat.edu.pl

Konrad WOJTOWICZ
Faculty of Mechatronics, Armament and Aerospace
Military University of Technology
Warsaw, Poland
konrad.wojtowicz@wat.edu.pl

***Abstract*—Formula One (F1) car testing requires high-precision measurement systems to collect and analyze car performance data. However, designing measurement systems for F1 cars presents numerous challenges due to the extreme operating conditions and stringent requirements for accuracy and reliability. This paper reviews recent research on the design and development of measurement systems for F1 cars, highlighting the challenges that must be overcome in order to achieve accurate and reliable data collection. The paper also addresses the problem of difficult access to research (a small number of publications due to Formula 1 teams' reluctance to share knowledge) related to testing sensors used in F1 cars. In addition, the concept of possible laboratory tests on the resistance of sensors to overloads occurring during the race was presented. A laboratory stand for performing such tests has been presented. The paper concludes with a discussion of potential future directions for research in this field.**

***Index Terms*—sensors, Formula One, measurement, data collection**

I. Introduction

Formula One (F1) racing is a highly competitive and technologically advanced sport that requires high-precision measurement systems to collect and analyze car performance data. However, designing measurement systems for F1 cars presents numerous challenges due to the extreme operating conditions in which the cars operate. These conditions include: [1-5]

- High speeds:
  F1 cars can reach speeds of up to 360 km/h, which places significant demands on the measurement systems in terms of accuracy and response time;[6]
- High G-forces:
  F1 cars experience high levels of acceleration and deceleration, reaching up to 5 G's. The measurement systems must be able to withstand these forces and maintain accurate readings;[6]
- Vibrations:
  F1 cars generate significant amounts of vibration, which can affect the performance of the measurement systems and lead to inaccurate readings;[6]
- High temperatures:
  The engines of F1 cars generate high temperatures, which can impact the accuracy and reliability of the measurement systems;[3,5]
- Electromagnetic interference (EMI):
  The presence of multiple electronic systems in the car and the use of wireless telemetry systems can lead to EMI, which can affect the performance of the measurement systems;[7,8]

These extreme operating conditions require measurement systems that are highly accurate, reliable, and robust enough to withstand the harsh environment of F1 racing. Around 250 sensors are placed on a Formula One car during a race. Each can be assigned to one of three categories: control, instrumentation, and monitoring. The correct operation of each of them is of great importance. Loss of data from some sensors can damage individual components of the system and thus generate huge costs needed to repair the car. Moreover, sensor errors can negatively affect the car's operation and, as a result, lose the chance to win the race, which translates into actual financial losses. For this reason, engineers and teams of mechanics attach great importance to their design, testing, and continuous improvement.[9]

II. RELATED WORK

Recent research on the design and development of measurement systems for Formula One cars has focused on developing new technologies and techniques to improve data collection and analysis accuracy, reliability, and efficiency. The following are some critical research areas [2,9-13].

A. *Telemetry systems*

Research has focused on developing new telemetry systems that transmit high-resolution data in real-time, with minimal latency, while minimizing the risk of electromagnetic interference (EMI). One approach has been to use optical fibers for data transmission, which can provide high-bandwidth, low-latency communication without the risk of EMI.[5,14-17]

B. *Vehicle dynamics measurement systems*

Research has focused on developing new measurement systems that accurately measure the car's dynamics, including acceleration, deceleration, and lateral forces. One approach has been to use inertial measurement units (IMUs) and GPS sensors to provide highly accurate data on the car's position, velocity, and acceleration. [18,19]

C. Comprehensive measurement systems

Research has focused on developing comprehensive measurement systems that can collect and analyze data from multiple sensors and systems in the car. It includes developing new software algorithms to process and analyze large amounts of data in real time, enabling teams to make informed decisions quickly.

D. Additive manufacturing

Research has also focused on using additive manufacturing (3D printing) techniques to develop lightweight and highly precise measurement systems that can withstand the extreme operating conditions of F1 racing. [20-22]

Bearing in mind the fact that the reliability of the measurement systems depends not only on the proper functioning of the car but also on the health of the driver, who, in the event of any failure while driving at speeds often exceeding 300 km/h, does not always affect the behavior of the car, engineers, designers, and technicians pay particular attention to the quality of the sensors used. The stringent requirements for accuracy and reliability that can be distinguished in Formula 1 are [5, 7,13-17]:

- High resolution:
  F1 teams require measurement systems that can provide high-resolution data to enable them to make precise adjustments to the car's setup;
- Low latency:
  The measurement systems must be able to collect and transmit data in real time, with minimal latency, to enable the team to make informed decisions quickly;
- High sampling rate:
  F1 cars generate a large amount of data, and the measurement systems must be able to capture this data at a high sampling rate to provide accurate and detailed information about the car's performance;
- Robustness:
  The measurement systems must be able to withstand the harsh environment of F1 racing, including extreme temperatures, high G-forces, and vibrations, without compromising their accuracy or reliability;
- Accuracy and precision:
  The measurement systems must provide highly accurate and precise data to enable the team to make informed decisions about the car's setup and performance;
- Reliability:
  The measurement systems must be highly reliable, with minimal downtime, to ensure the team can access accurate and timely data throughout the race weekend.

Most of the articles related to measuring a Formula 1 car's technical parameters are focused on developing new systems for collecting, processing, and transmitting data obtained during the race. Few works focus on assessing whether the sensors used for measurements are resistant to overloads, high speeds, vibrations, or the influence of electromagnetic interference during driving. Additionally, no research works to determine how long a given sensor can be subjected to such external factors before it is destroyed or starts to give fake data.

III. THE PROPOSED METHODOLOGY

For testing purposes, it was decided to build a measuring track (Fig. 1) capable of reaching overloads of 7.5G. A drive system with a linear motor with a movable primary part powered by three-phase alternating current was used for its construction. It was decided to use the MCL020D coreless motor from Bosch Rexroth. Thanks to such a solution, it is possible to adjust the "measuring trolley" speed precisely. MCL coreless linear motors have low weights, high precision, and high speeds. They differ from the core version in designing the main unit made of non-ferrous metals with a three-phase copper winding embedded in resin. Thanks to this design, there are no pulling or holding forces between the primary and secondary parts. These aspects, combined with the relatively low moving mass of the body, ensure very high dynamics and, at the same time, are characterized by high precision.

Fig. 1: Measuring track with MCL020D coreless motor.

It was decided to use the Bosch Rexroth EFC 3610 inverter to power and control the station's motor driving (Fig. 2). It is a versatile and economical frequency control device providing platform speed control. It uses V/f control technique. Thanks to its many applications, it is characterized by easy installation and commissioning and a large power range. Its additional advantage is the built-in braking module with a power of up to 2.2 kW.

Fig. 2: Inverter Bosch Rexroth EFC 3610.

Fig. 3: VN-200 GNSS/INS device.
https://www.vectornav.com/products/detail/vn-200

TAn inertial navigation system made by VectorNav has been chosen to measure acceleration. VN-200 (Fig. 3) is a miniature, high-performance GNSS-supported Inertial Navigation System (GNSS/INS) featuring 3-axis gyroscopes, accelerometers, magnetometers, a high-sensitivity GNSS receiver, and advanced Kalman filtering algorithms.

IV. RESEARCH PROCEDURE

The tests consist of multiple accelerations of sensors installed on the stand (such as temperature or pressure sensors). During the research, the tested sensors continuously measured the set parameters. Based on the tests, it is possible to determine the service life of individual sensors and to check whether they show the same values when exposed to overload and how they work in normal conditions. The crucial element of the laboratory stand is its drive. It determines the area in which it can be used. The test stand used a drive system with a linear motor with a movable primary part powered by three-phase alternating current.

During the calibration and control tests on the laboratory stand, an overload of up to 7.5G was achieved. The overload depends on the frequency of the inverter operation. (Fig. 4)

CONCLUSION AND FUTURE WORKS

The built stand for testing sensors operating during overloads similar to those occurring during the formula one races fulfills its task. Depending on the selected parameters, obtaining up to 7.5G overloads, which coincide with those achieved during races, is possible. It is possible to consider extending the motor runway to carry out tests in which the sensors are loaded at one time for a more extended period than now. Designing measurement systems for Formula One car presents significant challenges due to the high speeds, complex mechanical and electronic systems, and extreme conditions experienced by these vehicles. Accurate and reliable data is critical for teams to optimize performance and make informed decisions during races. One of the biggest challenges in designing measurement systems for Formula One cars is managing the massive amounts of data generated by the numerous sensors and instruments installed in the vehicles. Additionally, the systems must be designed to operate under extreme conditions, such as high temperatures, vibrations, and G-forces. Despite these challenges, significant progress has been made in recent years in developing sophisticated measurement systems that provide teams with precise and detailed information about the performance of their vehicles. These systems are crucial in helping teams to improve their cars and gain an edge over their competitors. Moreover, several research areas could help further improve measurement systems for Formula One cars. One of the most promising areas is the development of more advanced artificial intelligence and machine learning algorithms that can analyze the vast amounts of data generated by these systems in real time. Another area of research is the development of more robust and resilient measurement systems that can withstand the extreme conditions experienced by Formula One cars. It could involve using new materials and designs and improving manufacturing and testing processes. Finally, there is a need for ongoing research into the most effective ways to integrate measurement systems with other aspects of Formula One racing, such as vehicle design, aerodynamics, and driver performance. By combining

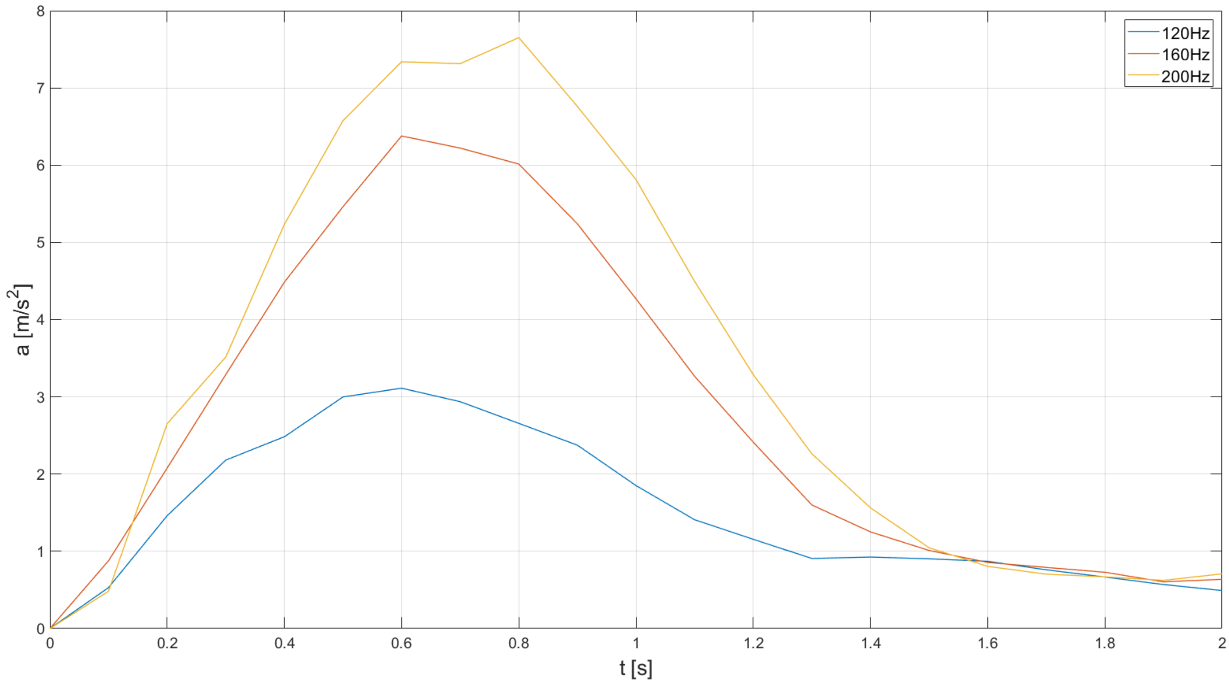

Fig. 4: Plot of accelerations achieved by the stand over time for different frequencies.

data from multiple sources, teams can better understand their cars and make better decisions during races.

REFERENCES

1) J. C. Sánchez-Molina, J. M. Espín, and A. Alcolea. ”Design of a measurement system for monitoring the deformation of Formula One racing car chassis.” *Measurement*, vol. 145, pp. 621-630, 2019.
2) J. Waldo, ”Embedded computing and Formula One racing,” in IEEE Pervasive Computing, vol. 4, no. 3, pp. 18-21, July-Sept. 2005, doi: 10.1109/MPRV.2005.56.
3) Martelli, P.P. Formula 1 — Engine and chassis control unit. AutoTechnol 1, 38–40 (2001). https://doi.org/10.1007/BF03246604
4) T. Erol, A. F. Mendi and D. Doğan, ”Digital Transformation Revolution with Digital Twin Technology,” 2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), Istanbul, Turkey, 2020, pp. 1-7, doi: 10.1109/ISMSIT50672.2020.9254288
5) G. Danese, M. Giachero, F. Leporati, N. Nazzicari and M. Nobis, ”An Embedded Acquisition System for Remote Monitoring of Tire Status in F1 Race Cars through Thermal Images,” 2008 11th EUROMICRO Conference on Digital System Design Architectures, Methods and Tools, Parma, Italy, 2008, pp. 432-437, doi: 10.1109/DSD.2008.55
6) L. Cocco and P. Daponte, ”Metrology and Formula One Car,” 2008 IEEE Instrumentation and Measurement Technology Conference, Victoria, BC, Canada, 2008, pp. 755-760, doi: 10.1109/IMTC.2008.4547138
7) D.J.N. Limebeer, G. Perantoni and A.V. Rao, “Optimal control of Formula One car energy recovery systems”, International Journal of Control, 87:10, 2065-2080, 2014,DOI: 10.1080/00207179.2014.900705
8) G. Perantoni, D.J.N. Limebeer, “Optimal control for a Formula One car with variable parameters”, Vehicle System Dynamics, 52:5, 653-678,2014, DOI: 10.1080/00423114.2014.889315
9) S. Tourette, G. Collin, P. Le Thuc, C. Luxey and R. Staraj, ”Small meandered PIFA associated with SAW passive sensor for monitoring inner temperature of a car exhaust header,” 2009 IEEE International Workshop on Antenna Technology, Santa Monica, CA, USA, 2009, pp. 1-4, doi: 10.1109/IWAT.2009.4906888.
10) M. Naveen Kumar, V. Jagota, M. Shabaz, ”Retrospection of the Optimization Model for Designing the Power Train of a Formula Student Race Car”, Scientific Programming, vol. 2021, Article ID 9465702, 9 pages, 2021. https://doi.org/10.1155/2021/9465702
11) C. Wallin, L. Gustavsson, and M. Donovan, ”Engine Monitoring of a Formula 1 Racing Car Based on Direct Torque Measurement.” SAE Transactions, 111, 512–517,2002. http://www.jstor.org/stable/44743080
12) C.M. Crewe, et al. “Measurement of Formula One Car Drag Forces on the Test Track.” SAE Transactions, vol. 105, 1996, pp. 2114–20. JSTOR,

http://www.jstor.org/stable/44720928. Accessed 19 Mar. 2023.

13) Bitar, Sami, et al. “Development of a Magnetoelastic Torque Sensor for Formula 1 and CHAMP Car Racing Applications.” SAE Transactions, vol. 109, 2000, pp. 42–49. JSTOR, http://www.jstor.org/stable/44699106. Accessed 19 Mar. 2023.
14) B. Dixon, V. Kalinin, J. Beckley and R. Lohr, ”A Second Generation In-Car Tire Pressure Monitoring System Based on Wireless Passive SAW Sensors,” 2006 IEEE International Frequency Control Symposium and Exposition, Miami, FL, USA, 2006, pp. 374-380, doi: 10.1109/FREQ.2006.275414.
15) R. D. Knowles, A. J. Saddington, and K. Knowles, ”On the near wake of a Formula One front wheel,” *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 227, no. 11, pp. 1491-1502, 2013, DOI: 10.1177/0954407013491903.
16) L. Cocco and S. Rapuano, ”Accurate Speed Measurement Methodologies for Formula One Cars,” 2007 IEEE Instrumentation and Measurement Technology Conference IMTC 2007, Warsaw, Poland, 2007, pp. 1-6, doi: 10.1109/IMTC.2007.379160
17) P. Bere, C. Neamtu, ”Methodology for evaluate the form deviations for formula one nose car.”, cent.eur.j.eng 4, 148–154 (2014). https://doi.org/10.2478/s13531-013-0158-x
18) Y. Shimasaki, H. Maki, J. Sakaguchi, K. Nishizawa, et al., ”Study on Combustion Monitoring System for Formula One Engines Using Ionic Current Measurement,” SAE Technical Paper 2004-01-1921, 2004, https://doi.org/10.4271/2004-01-1921.
19) A.J. Saddington,R.D. Knowles, and K. Knowles, ”Laser Doppler anemometry measurements in the near-wake of an isolated Formula One wheel”. Exp Fluids 42, 671–681 (2007). https://doi.org/10.1007/s00348-007-0273-7
20) Y. S. Saurabh, S. Kumar, K. K. Jain, S. K. Behera, D. Gandhi, S. Raghavendra, and K. Kalita, ”Design of Suspension System for Formula Student Race Car,” in *Procedia Engineering*, vol. 144, pp. 1138-1149, 2016, International Conference on Vibration Problems 2015, ISSN: 1877-7058, DOI: 10.1016/j.proeng.2016.05.081
21) Chen, T. Li, J. Zeng, Y. H. Lu, and L. M. Zhang, “Vibration Transfer Analysis of High Speed Train Considering Car Body Flexibility.”, Advanced Materials Research. Trans Tech Publications, Ltd., December 2012. https://doi.org/10.4028/www.scientific.net/amr.605-607.1168.
22) P. G. Wright, ”The influence of aerodynamics on the design of Formula One racing cars,” *International Journal of Vehicle Design*, vol. 3, no. 4, pp. 383-397, 1982, DOI: 10.1504/IJVD.1982.061285.