PRIMENA LASERA U AUTOMOBILSKOJ INDUSTRIJI

APPLICATION OF LASERS IN AUTOMOTIVE INDUSTRY

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Uloga lasera i sprežanja sa solarnom energijom i problemima „tematike“ vozila je vrlo široka. U ovom radu su analizirani principi, savremeni razvoj specifičnih disciplina i posmatranja sa tehničko/ naučno/ inženjersko/ metroloških tačaka gledišta. Ova oblast je u širem smislu vezana za „istoriju“ naše planete ili, u užem, sredinu prošlog veka i zlatno doba kvantne elektronike. Neki od generalnih problema su rešavani sporo, ali sa druge strane, posmatranjem sadašnjeg stanja nekonvencionalnih napajanja vozila/ automobila i realizovanih komponenti, neke karakteristike su menjale konvencionalne pristupe realizovanju i kapacitansama u sistemima napajanja. Glavni cilj je da se analiziraju problemi koji bi rešavanjem povećali gradijente budućeg razvoja solarne energije i njene primene u automobilskoj industriji, putem multidisciplinarnih pristupa. Uz podsećanja na potrebe, razmotrena su sprežanja kroz teoretsko inženjerske pristupe u polju tehnologije, metrologije i generisanja snage/ energije, i transformacije u području razvoja, primene i rada lasera, automobila i solarne energije.

Ključne reči: laser; Sunce; obnovljivi izvori energije; vozilo; tehnologija; metrologija; solarno pumpanje lasera; holografija; plazma

Laser role and couplings with vehicles and solar power are numerous and in this paper we analyzed the principles, contemporary development of special areas and observation from the scientific/ engineering, or from the metrological point of view. This area is, in broader sense, connected to history of our planet, or since the midst of the previous century and golden age of quantum electronics. Some of the general problems have rather slow dynamics of solving, but on the other hand, considering contemporary state-of-the-art of unconventionally powered vehicles and realized components, some characteristics change conservative opinions on the realizable capacities. The main goal of this consideration is to point to the unity of problems, which might speed up the gradients of the developments in solar technology of automotive technology, by multi-disciplinary approach. Overall, we have considered both theoretical approaches and currently developed systems in the fields of technology, metrology and power production and transformation.

Key words: laser; Sun; renewable energy sources; vehicle; technology; metrology; solar laser pumping; holography; plasma

1 Introduction

Main parts of electrical power system bring to mind the importance of electrical power, production, distribution, consumption and production capacities of Serbia and neighboring countries

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(BiH - Republic of Srpska, Montenegro, Romania), as well as Europe and other continents. There are issues of small/ large hydro-, thermo-, wind and geothermal power plants and systems (and others) concerning planned and realized capacities. Wind energy transformation, properties of energy, transmission/ distribution/ development of networks, distribution facilities, photographs, questions of consumers and areas, generation of local area diagrams and averaging of capacities are still contemporary topics. The question and the stance of education of necessary theoretical and practical knowledge, as well as the skills for education systems are of special importance. Detailed data regarding climate and weather, like wind charts, etc. should be constantly recorded, due to (debatable) changes of climate.

1.1 Sun and wind

Almost entire renewable energy and also fossil fuel energy originate from the Sun's energy. Sun as a star rotates with the speed of 30 km/s around its axis with period of 27 days at Sun's equator and of around 31 day at Sun's poles. In the core, temperatures are estimated at 10^7 K, pressure 10^{14} Pa and density 10^5 kg/cm³. Here the thermonuclear fusion of hydrogen to helium takes place, generating vast quantity of energy which is transferred to the surface and from there transmitted into Space in the form of electromagnetic radiation.

Photosphere, chromosphere, corona (seen during eclipse) and heliosphere (reaching out towards Space) are areas which parameters are expressed with temperature - T , pressure - p , radiation/ solar constants, state of ionized particles and gases. The temperature at the photosphere is $T = 5769$ K and radiating power 64MW/m. Sun attributes, like the change of irradiation power with the distance from the Sun to the Earth is decreasing and solar constant drops to ≈ 2353 W/m. The causes of wind formation could be found. One parallel is that laser motor was known although it did not work on laser with solar drive. Other parallels are lasers pumped by solar power.

For a long time, Germany was leading in wind power production capacity. In 2008 Germany had dropped to the second place and in 2010 to third, with the China taking the precedence. The development of wind energy in the first two decades of the 21st century and the factsheet on the wind power in Germany from various references are shown, Figs. 1-3. Consumption management in the smart power grids with variable production puts on line issues: electrical power, distributed sources, smart network, response, consumption, load, prognosis, management, peak power, variable production. Nowadays, economic and ecologic interests are often opposed and are the topics of everyday consideration and debate [1-22].

Figure 1. Wind power in Germany from 1990 to 2015 [2]

Figure 2. Development of wind energy supply in Germany

2 Technological and metrological application

The use of lasers in automotive/ vehicle industry, aircrafts and shipbuilding - maritime industry [23-27], for civil and military purposes is increasing. Historically, a series of references describing application of lasers in certain area of everyday life contain it as a topic. As devices, lasers were developed in scientific disciplines worldwide and used in advances to Space, medicine, in art and heritology as well [23-27]. Here, several examples are presented existing in generally all categories

covering material processing [27-34], a role in vehicle sensors, state of tires and similar, concluding with laser motors (engines) and laser rocket engines (motors) [35-54].

Figure 3. The factsheet on wind power in Germany in 2016 [1]

The application of lasers in automated visual inspection systems, quality management and in the measurement technique of vehicle production and control are among the measurements developed on the basis of coherent sources for non-destructive testing (NDT) of: fatigue, vibration, deformation, flow and combustion processes. The attributes are: simplicity, easy handling, ergonomic design of the car interior, methods of geometric and physical optics, profiles and surface positions, detection of defects and optical vibration measurement and monitoring.

To control oil purity and combustion processes, a number of spectroscopic methods are used. For other features linked to automotive industry and vehicle operating, laser based methods of frequent use are anemometric methods, interferometry, holography, tomography, however speckle based methods are also implemented. In many methods, quantum generators are widely used as sources. In the field of precision mechanics and analogous problems, Moiré methods were known as more classic. Some developments that are linked to all the methods mentioned above are: CCD batteries and the development of small computers including more *conservative classical methods*.

In *pure* processing of materials in automotive industry, laser role is included through the tasks of engraving, printing on metal parts, drilling, cutting, welding (machining/ processing of objects of various geometries), printing through glass or layers of other material, after the system has been assembled. Printing techniques are known in the methods of masks (in photolithography) and matrix or scaffolding in 3D printing and are connected to branching procedures and artificial intelligence. Monitoring by camera is also performed in the vehicle industry, especially in the automotive industry. The trend in general is to replace the human work with robotic or digitalized solutions. Once upon a time, acquiring an image of a work piece in good illumination was sufficient for further analysis, which excluded the necessity to observe or to have access to the work piece. Pro-

cessing speeds and solutions depend on the complexity of the part to be produced and the current technology. In perspective, the quality of acquired images improves with illumination by coherent sources. As an example, lasers were included in bar code technology much later after it was introduced. Much of the theoretical work has been invested and many technological operations were developed until laser centering of automotive parts became common in many car repair centers in *almost every town*. A large number of possible, potential or current laser applications are sketched in Fig. 4.

Figure 4. Typical points of inspection and quality control in vehicles. Emphasis is on the measuring role of the quantum generator, but it was not taken into account that the laser methods also participated in the construction of a particular component or assembly

Characteristic places of inspection and quality control in vehicles are steering wheel and measuring elements, engine, drive unit, electronics, exhaust gases, interior equipment, car body, centering of gears and wheels, control of tires, corrosion testing, measuring of vehicle speed and wheel rotation speed, topographic types of control, performed at normal speed of movement. For instance, poorly centered pneumatics cause vehicle vibrations and have serious impact on the car suspension and support system. The implementation of such systems, Figs. 4-8, has been developed by car and tires manufacturers, Michelin among the others.

Figure 5. Control (monitoring) of tires with a laser beam

Profile and surface quality examination, and the surface position measurement are also performed by laser. In contour measurements, a sharpened probe is used maintaining the mechanical contact with the surface of interest. Changing the position causes the probe to move, which further evaluates the contours of the surface profile. Mechanical devices in various areas verify the thickness of details and determine the surface parameters in the process of automatic control by using the servo systems and feedback by adequate comparison. For the exact reproduction of the 3D representation, the method of profilometry of the template is used.

Optical solutions in profilometry have the following advantages: no damage to the work surface, no wear of instruments, measurements can be performed with templates made of various mate-

rials. Developed models range from polished materials of various degrees of metal surface quality to plastic and matt surfaces. Accessories with wedge-shaped components and topography recording are increasing in numbers. Measurements provide a profile, horizontal map, object thickness, as in Fig. 9a.

Figure 6. Control of a tyre with a laser beam [24]

Figure 7. Displacement measurement scheme

Figure 8. Laser displacement measurement [25]

Figure 9. a) Block diagram for measuring the surface profile; b) synchronous detector output

In the surface profile measurement system, Fig. 9, the laser beam is focused at a small spot on the surface of the examined object. Scattered radiation is collected by lenses and focused through

the diaphragm vibrating at sound frequencies onto the photodetector. The variable component is amplified and detected by synchronous detection in relation to the frequencies of the generator. Diaphragm dimension is 250 μm , and vibration frequency is 525 Hz. The sign of the output signal depends on the direction of movement in relation to the focus. This is how maps are recorded (2D analysis).

2.1 Systems for defect search and diagnostics

The advantages of laser quality inspection and control methods come to the fore when it is difficult to provide automatic control. There are various cases: surface quality, mass production, rapid control of multilayer materials, small details in the automotive industry. The system works on the principle of light scattering (laser beam). For cylindrical geometry, the He Ne laser beam is transformed into a line, which follows the workpiece with a mechanical manipulator of the auto-revolver type. Various optical signals are collected from the surface of the working part, transmitted through a system of fibers and other optical elements, and detected by a photomultiplier. The frequency spectrum of the obtained signals is compared with/ to the spectra obtained from the surfaces without defects.

2.2 Optical vibration measurements

The character of vibrations of one structural part during harmonic excitation is measured. Complex processes in engines, brakes, body parts and testing areas at several points can be analyzed. For instance, Volkswagen used the contactless methods for obtaining the data for analysis, holographic and laser Doppler measurement techniques. Among them, there are two-pulse holography, LDA measurements of vibrations in small volume (SOVAS technique); Tabs.1 and 2 give characteristics of laser methods during time.

Table 1. General methods of vibration measurement

	Real time holography	Pulse holography	SOVAS
Object	Single construction elements	Construction blocks, aggregates, chassis	Construction blocks, aggregates, movable parts of chassis
Measuring quantity	Amplitude	Analysis regarding laser pulse	Speed
Measuring interval	0.2 μm - 0.5 μm	0.2 μm - 200 μm (extrapolated)	0.001 m/s - 1 m/s
Excitation	Harmonic	Harmonic or auto-excitation	Harmonic or auto-excitation and excitation of noises
	Frequency variation	Dominant frequency time filtering	Spectral analysis
State of vibrations	Forced	Transitional regime	Stationary regime
Mode of operation	Surface	Surface	30 dots $\times$ 30 dots
Duration of measurement	Several seconds	Instantly	10 s - 300 s

Table 2. Methods of holographic interferometry

	Real time holography	Pulse holography	Holographic interferometry with averaging in time
Operations	Hologram exposure, loading the object	Hologram exposure, loading the object, secondary exposition	Hologram exposure during object moving and development
Advantages	Total information on object changes	Easy realization, one-for-all single setup, constant emulsion	Easy realization and easy interpretation of results
Drawbacks	Difficulties in interpretation, necessity of repeating the setup, emulsion, distortions	Pure information, difficulties in interpretation	Not suitable on immobile surfaces

Applications	Analysis of mechanical stresses, defects	Analysis of mechanical stresses, defects, Analysis of transitional processes	Analysis of vibrations
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2.3 Active holography - real-time holography

With the help of a real-time holography, the vibrations caused by the construction elements are visualized. The vibration distributions are observed on a monitor with a video camera. Resonances are established by varying the excitation frequency. The measuring area relates to the area of the interference fringes $0.1\ \mu\text{m} - 5\ \mu\text{m}$. The interferometer must be on a special stand with insulation from vibrations of a mechanical nature. There is also the holographic working camera, the control of the illumination of the object, excitation and the stroboscopic device. For structural vibrations of the engine block, the range above 1 kHz is reached.

Another application with laser technique is related to the technique of optimization of brakes from the stress-strain point of view, Fig. 10. The problems of real-time holography are related to: a) placing the hologram in the exposure position, b) distorting the photoemulsions and c) detailed interpretation of the interference image in relation to the theory of local zones.

Figure 10. Vibration: technical optimization by holographic interferometry

Figure 11. Holocamera

2.4 Two-pulse holography

Pulse holography has long been used outside of optical laboratories. Illumination with two pulses is used for the analysis of transient modes with a holocamera and adequate electronics, Figs. 7, 10, 11, which evaluate the vibrations (displacement/ dynamic) of the car body and the sub-systems. Free and forced vibrations are monitored. The resulting interference distribution showed the exact position and time (moment) of the vibration at a certain frequency. In addition, structural material weaknesses, noise sources and material strength are also examined. One of the first applications of holography in general, including this method, is based on the examination of pneumatics and defects in production and exploitation, Figs. 12, 13. Compared to the methods of real-time HRV holography, the method is less flexible and cannot monitor continuous deformation. The problems are in the interpretation, localization of zones, etc., Figs. 13, 14. The existence of both defects and places of different loads causes the occurrence of thickening and deformation.

Figure 12. Holographic tests of tires; interference fringes

Figure 13. Detail of hologram for defect analysis

Figure 14. Changes on disk couplings examined by holographic techniques (mechanical and thermal stresses)

2.5 Laser Doppler methods: LDA and LDV

Holographic interferometry, HI, with time averaging does not demand that the detail, the construction ensemble and the scene are without vibrations of the environment (“without moving”), and that mechanical displacements are less than $\lambda/4$, where λ is the wavelength of the applied quantum generator. The characteristic of the beam intensity dependence on x , taken by one of the holographic schemes, is connected to $D(x)$ – surface displacement from the equilibrium state (or undeformed state) – and to λ . The surface analysis and estimation of its dynamics is possible if the condition $4\pi D/\lambda \gg 1$ is fulfilled.

In general, if the Doppler effect is present, the methods inherit its name. It is often used with the systems that follow both the development of techniques/ technology and the widening of our experience from acoustics to area where relativistic effects had to be taken into account for the case of EM radiation. HI methods are based on the optical path manipulation and on obtained visualization of hologram. The image is closely connected to vibrations, resonant frequencies, provoked deformations, and stresses of the objects or system. The vibrometer uses the direct and referent beams. Laser beam reflected from the object is recorded in the measuring system. The laser beam operates with defined number of measuring. In the case of vibrations, vibration processes are imprinted in signals. The obtained spectrum is the principal task for analysis and from the depth of modulation characteristic (resonant) frequencies and the local distribution of the vibrations can be obtained, Figs.15. Besides the first known application in violin resonator (or other musical instruments), and in turbine blades, HI methods with time averaging are applied in automotive, aircraft and other vehicle industries.

Figure 15a. SOVAS techniques define resonance frequencies of component, part of the system or in general recorded area (valve dynamics)

The analyses of the combustion processes have been performed by the methods of laser beam scattering and have been used for monitoring of engine operation, and for monitoring of turbulent processes. The Schlieren method is commonly used in this case, Fig. 15b.

Figure 15b. Schlieren method applied in motor dynamic control/ monitoring

2.6 Laser Rocket Motors

New trends in the development of rocket techniques have opened new possibilities for lasers to be implemented and for solving problems related to classical motors used in interplanetary flights. In this paper, some aspects of the design and construction of laser rocket motors as well as the implementation of exchange of laser power are presented. A lot of debate concerning the types of optimal design of the systems of energy transformation in cosmic investigation still exists, and new technologies in recent years have opened up many new possibilities.

Laser rocket motors run on various energy types: electrical (electrostatic, electromagnetic and electrothermal), nuclear, solar, magneto-hydrodynamic and numerous types of chemical fuel, and

more. They all have many advantages and disadvantages, with different degrees of efficiency. Solar-powered laser motors also exist. Both solar into thermal energy transformation and motors (ionic or plasma) are considered for the cosmic travel. However, it seems that the ideas concerning classical – thermal – motors are still dominant in the field of contemporary solutions in the Earth's atmosphere. The link between reactive motors and laser as a power source is still a topic of discussion as also is the grouping of laser power transmission into several groups based on the principle of operation, thermal, electric and hybrid.

One possible solution of laser implementation is where a directed, focused laser beam is absorbed in some solid, liquid or gas fuel, or for laser-ignited combustion, Fig. 16. The basic mechanisms of absorption in heat exchange devices are: Bremsstrahlung radiation, CW absorption, molecular absorption and particle-level absorption.

The implementation of pulsed, periodical laser beams, or CW laser beams depends on the combustion material type. The essential part of the design is linked to the current generator in the motor nozzle. In our terminology, the motor nozzle means establishing plasma in the working material, and combustion is the main process in sustaining the plasma.

The aerodynamic windows are especially important when working with high-power lasers. There exist non-linear optic solutions in surmounting window-related problems; these solutions are based on multi-layered materials and inverse-population processes. Optoelectronic systems are used for energy transport from Earth to orbital stations; the purpose of these systems is the transmission of CO₂ and free electron laser beams, Fig. 17.

Figure 16. Laser-ignited combustion [50]

Figure 17. One of the first schemes of transmission of energy from free electron lasers on Earth to cosmic satellites. This scheme relies on the application of reflection and refraction processes

The station is built on high altitudes to minimize loss of power/ energy in the atmosphere. The principal parts of the system are: the free electron accelerator, powering sources, vacuum pumps, the transmitting mirror, the optical resonator, the collector/ concentrator of radiation; beam trajectory, geostationary orbital retranslator, etc. The feedback with the power station and the interorbital rocket with laser motor are also important aspects of the complex.

Laser rocket motors produce pressure based on the transformation of the beam energy into kinetic energy of fuel molecules via heating and expansion processes in the nozzle. The gases involved are of low molecular mass, and are therefore heated to very high temperatures. The principal tasks for the practical realization of motors of this type are: fulfilling the conditions for optimal absorption mechanisms of the laser beam, selection of the wavelength, the minimization of energy losses in all phases of motor's functioning, the design of the motor, and even the choice of materials or fuel, Figs. 18, 19.

Characteristic values are linked to simple approach to 1D modeling of flow, cylindrical geometry of the nozzle of constant cross section. These are the first approximations related to the real absorption of the laser beam, when effects of detonation, laser plasma wave transmission, supersonic processes and deflagration are possible. For CO₂ laser beam wavelength and hydrogen, at 0.1 MPa, power threshold is 10^{10} W/cm².

In Figs. 21-22, some characteristic results and facts from literature are presented.

Figure 21a. Places of some high power lasers and atmospheric transmittance [54]

Figure 21b.

Figure 22. Gabarites in contemporary systems.

3 Laser Cladding on Exhaust Motor Valves

3.1 Plasma and Laser Cladding on Stainless Steel for Exhaust Motor Valves

The exhaust motor valves are exposed to high temperature of hot combustion gasses, followed by the pressure at the contact surface with the valve seat. The valves for fossil fuel motors are manufactured from stainless steel materials, but many of which do not have satisfactory wear properties at high temperatures. The thermal stability can be improved by cladding. For that purposes, hard and corrosion resistant material should be used, such as Co- or Ni-based materials. Due to high boiling and melting points, the plasma spraying and laser cladding must be used for fast melting. Laser cladding is distinguished from plasma cladding in a smaller fusion area at the parent metal and in producing a well metallurgical bond of the hardfaced material. Furthermore, the combustion of vaporized liquid fuel produces specific kind of high-temperature corrosion. Many attempts have been done in choosing the material with adequate properties. The Ni alloys for motor engine valves must contain strengthening elements, commonly Co, Al, and Ti. Due to lower price, the Co coating alloys are superior to stainless steel as a surface material. The industrial acceptance of laser cladding is still slow.

Powders. Typical stainless steel for exhaust motor valve has contributions of five elements (percent): C (0.50), Cr (21.0), Mn (9.0), Ni (4) and N (0.4). After quenching from 1140 °C- 1180 °C in aqua, steel retains the austenitic structure; it means that hardness values are not increased. As corrosion resistant and hardfaced materials for exhaust motor valves, available are Ni-Cr-B-Si and Co-Cr-W alloys (Stellite 6 or similar) in powder form [27]. For melting of those alloys, the high energy welding methods should be used.

Characteristics of cladding methods for engine valves. The contact surface between the engine valve and its seat, assigned by an arrow in Fig. 23a, subjected to the pressure in the atmosphere of combustion gases, achieves a remarkable wear. In order to decrease the wear, surfaces should be cladded/ hardfaced, Fig. 23b. This surface is rough, Fig. 23c, and has to be grinded.

Figure 23. a) Contact surfaces between valve and seat, b) Surface during cladding, c) Cladded surface at the edge of motor engine valve

It is possible to achieve high energy torch in the plasma gun (*plasmatron*), Fig. 24a, where the stream of high velocity gases does not carry the molten particles. The plasma gun enables achieving high temperatures (> 4000 K), fast and strong stream of formed plasma gas, so that different powders could be melted at the valve edge.

The laser beam produces high temperatures in interaction, even more than plasma torch. Powder for laser cladding could be fed from one or both sides, Fig. 24b. It is possible to produce a thinner layer by laser beam than by plasma torch. One of the main advantages of laser beam is in lower dissipation of an expensive powder material to be melted and cladded. Depending on used powders, the hardness values of cladded material range from ≈ 390 HV to ≈ 550 HV. It is reasonable to consider hardfacing. In plasma or laser cladding, different technological parameters are applicable in a wide range: speed of beam travel, powder mass flow rate, used plasma or shielded gas, pulse frequency, energy of beam, etc.

Figure 24. Cross section through: a) plasma gun and b) laser head, for cladding;
1-W electrode, 2-Cu nozzle, 3-cooling water, 4- created plasma, 5-plasma stream, E-current source

For laser cladding of Co alloys, when sufficient energy of the beam reaches levels of > 18 J/pulse, CO_2 or pulsed Nd^{3+} :YAG lasers are used [27]. Heat affected zone, HAZ, and especially interface layers are very small after laser cladding, Fig. 25. The pores occurring in microstructure after laser cladding are rare and small, Fig. 25a.

Figure 25. Microstructures of cladded layers: a) stellite-6 layer and small interface on the parent metal; b) parent metal (left), HAZ and Ni-Cr-C-S alloy (right), magnification 300 $\times$ [27]

The dilution of cladded layer with parent material is higher with plasma method than with laser cladding method. Surface roughness, R_a , after grinding of cladded layer on motor engine valves [27] has to be on level < 1.8 μm .

Following statements are for further analysis. Plasma and laser claddings are cost effective methods for improving the wear- and corrosion- resistance characteristics of motor engine valves. Therefore, for surfaces, a material with better properties than the parent metal must be used. After cladding, the surface is rough. Industrial lasers are controllable power sources, meaning that the control of the heat input into the workpiece is better with the laser cladding than with the plasma gun cladding. The plasma cladding gives significantly higher power input into the workpiece, which is usually disadvantage in the sense of higher distortion of treated machine component. Lower distortion means smaller grinding thickness, which is of importance for manufacturing schedule. In both processes, it is possible to employ high-hardness alloys, even mixtures containing WC, SiC or similar intermetallic compounds, for a variety of applications [27].

4 Conclusion

Characteristics of plasma and laser cladding methods could be emphasized as: plasma and laser methods for cladding of motor engine valves dominate in automotive industry. In laser cladding the higher power density is achieved at the small target area than in plasma method. Hard and corrosion resistant materials may be easily melted by both methods. Obtained hardness values are in closer relation to chosen chemical composition of clad material rather than the used method for deposition of a layer. The negative role of strong plasma stream is the blowing of powder material to be clad. The smaller dissipation of powder material is achieved by using laser beam instead of plasma torch. The dilution of melted layer is lower in laser than plasma cladding. Both methods are available for producing new parts, as well as in additive manufacturing and for rebuilding of partially worn surface(s).

The main branches of the field of laser processing are: the study of technical characteristics of laser systems and laser types, as well as the study of other optical components, mechanical systems and the specificity of the designed devices. Since the era of MILK and the first PhD theses in former Yugoslavia about the industrial applications of lasers, there have been numerous other studies about basic functioning and practical applications: namely, about laser pumping, beam shaping, transportation, reflection and refraction processes. There have also been studies about systems based on fluid mechanics, system cooling, thermostating for increasing laser stability. It is important not to forget about the social and health aspects of research, i.e. the education in the application of the developed systems and demand to provide the necessary protective measures. Note that some of the old terminology for the deviation of the actual results from the nominated/projected/ fabricated results (for example, drilling diameter, surface roughness, precise contour cutting) needs to be updated – for example, the term “error” should be replaced by “uncertainty”; this not just a matter of terminology. Considering the variable nature of energy transformation, a multidisciplinary approach is inevitable.

From the economic perspective, there is no doubt about the fact that quality is the best investment, and this is true for the vehicle industry as well. In order to establish a system of quality in the automotive industry, one must have: technical documentation depending on the type of the vehicle, production equipment, personnel, realization monitoring, environmental conditions and ecological trends.

Several highly trained people are required to study on large and complex array of machines. One engineer today with a laptop can do more sophisticated studies of much larger systems. Steady-state flows are simulated as the positive sequence equivalent, presented by several π sections connected in series. Each of them represents a length of line as shunt capacitors and series reactive elements. The system was replaced on a large panel, the face of which was a maze of physical connection links. Unbalanced faults required an interconnection of three networks, each one for positive, negative and zero sequence. Dynamics were simulated by a step-by-step process with some representation.

Lasers are used in various ways for technical verification purposes. New measuring methods for displacement and sizes are constantly being developed, but they are all based on geometrical and physical optics, diffraction, interference, holography, holographic interferometry, etc. Methods for the measuring of vibrations in general as well as stresses and stress distribution are also based on the aforementioned physical disciplines and processes. Many of these methods are in essence classical, where the laser is only a substitute for a natural source of energy; however, many others can only be realized with the use of lasers/coherent beams. The term “coherent” should be used both in the spatial and temporal sense, but in practice, it usually refers to only one of these two. Because of the development of lasers with very short pulse (ns-ps-fs), certain measurements, which could previously only be done in a laboratory, can now be performed in the field.

Laser measuring methods are often cheaper, simpler and faster than their more classical counterparts. Lasers are also used in systems which measure displacements caused by static and dynamical loadings, which are a very important aspect of monitoring in the automotive industry. One such example is the tuning and positioning of car suspension. Also, corrosion is nowadays monitored by

small portative devices. All of these processes are carried out from a distance, without interrupting the production processes. Laser-based microanalysis of materials (like LIBS, ...) has numerous advantages over other microanalysis methods (chemical, ion and electron beams, SEM and TEM, ...). Many practical applications rely on laser plasma. Laser-based microanalysis methods are very precise even for very small samples ($< 1\mu\text{g}$). There are numerous illustrations for the state of *know-how technology* and potential laser implementations.

Although they have their own histories, the topics of laser propulsion and rocket motors have connected several contemporary disciplines in recent years, initiating much theoretical research, as well as large international projects on the applied side of the areas.

A detailed examination of the comparison and current state of contemporary laser motors, which would consider both the theoretical and practical point of view, would necessarily be a very long/demanding project. Therefore, in this paper, only rough sketches of the subject matter have been given. From an educational point of view, one should neither dismiss the historical dynamics of the development of laser motors, nor the current state of today's most promising designs. The lasers have been given a special place in this paper, because many commercial and non-commercial quantum generators exist (laser transitions). One of the most important areas of research concerning lasers is the transfer of mechanical magnitudes by optical systems: buoyancy force or the transformation of electromagnetic energy to other ranges. In order to improve the functioning of laser motors, the most important aspect is increasing the efficiency of absorption (multi-layer material, coating, concentrator, etc.).

The theoretical foundations have existed for almost 30 years. The realization depends on both the needs and currently available technology. When minimizing losses in the application of lasers in motors, one must pay special attention to the processes in: plasma, transmission of energy to the working fluid, flow regulation, the mixing of hot and cold materials, the transfer of heat into the motor walls by convection and radiation, and in the protection of walls. Other important points of view include the gasodynamics of the flow through the plasma and the nozzle design. It is important to select the optimal laser wavelength for laser motors (engines), due to very large number of quantum generators. In particular, aerodynamical windows require many new solutions on their own. To reach the goals, the activities of today implement more and more, but efficient models, and also increase the level of approximation of the thermodynamic and other real processes. This can be achieved by developing better numerical models and more mathematical complex representation or mathematical symbolism/ formalism. The technical side consists of decreasing the project costs, increasing reliability, safety, "user-friendliness", simplification of design and ease of maintenance. The contemporary development of laser techniques is moving towards amelioration of laser beam characteristics and performance, stability (of frequency, polarization and mechanical one), increasing the range of applications and the choice of wavelength in the total range of the EM spectra and power (ranging from kW to MW). The emission and absorption processes in the atmosphere should be constantly studied and evaluated. That influences both the quality and the power magnitude of the laser beams entering the rocket engine from the station, located on the surface of the Earth. The contemporary development of material technology will lead to many new discoveries in the construction of new adequate materials with high hardness to temperature and pressure.

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5 References

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