The automotive industry is one of the world's largest by revenue and fast-growing markets. The rapid expansion was made possible by a rapid increase in the demand followed by smart design and manufacturing techniques. Alongside these, high attention was paid to environmental and safety reasons, which led to the necessity of weight reduction and strength increase of structural parts, thus inducing the development of complex components in High Strength Steels (HSS). The laser cutting technique proved to be most suited manufacturing approach to obtain complex shapes in reduced cycle times. Nonetheless, the machining process is yet not completely optimized since the limitation on the cutting speed generally arises from the limits of the kinematic chain and mechanical structure, rather than the technological process. In fact, the technological process would allow higher speeds from a theoretical standpoint.

The present Thesis was born from the collaboration between Politecnico di Torino and Efort-Europe. Specifically, the industrial partner had previously developed a robot prototype, designed for laser cutting of metal sheets for automotive field application. The robot presented a unique kinematic chain and remarkable motors performances. The geometrical imbalances due to the kinematic chain alongside the relevant accelerations caused the machine to suffer from inadequate static stiffness and high vibration levels due to resonant frequency excitation, especially in correspondance of the Tool Center Point. Moreover, the machine displayed inadequate damping and, consequently, poor accuracy during the cutting tests previously performed in Efort-Europe.

The objective of the Thesis was therefore to research, study and evaluate appropriate analysis methodologies as well as possible design and optimization strategies able to first characterize the machine from a dynamic standpoint, both experimentally and numerically, secondly to carry out a dynamic design in order to increase the cutting accuracy. A more in-depth description of the laser cutting process as well as of the machine, state-of-the art comparison, related challenges and objectives of the Thesis are reported in Chapter 1.

For the development of the present work, given the complexity of the problem, the effort was then re-directed along different paths, namely:

- experimental machine characterization from the dynamic standpoint;
- numerical models development;
- development of integrable solutions, i.e. Tunable Mass Damper (TMD);
- design optimization strategies.

As for the experimental characterization, no previous internal background related to this point was present in the company. The characterization had as primary objective the identification of the machine resonant frequencies. The added value coming from the research, though relying on limited resources, was the definition of a simple test plan and critical evaluation of the results without the need of relying on external sub-contractors to perform the characterization, thus inducing also economic benefits on the company side.

No previous background was present in the company also concerning the numerical models development, even though in literature their utilization is widespread for simple and complex cases. The main objective was to create machine digital twins in order to perform structural and dynamic analyses, create a reference dataset correlated to the experimental investigation and evaluate how the variation of the boundary conditions affected the machine performances. Specifically, one Finite Element (FE) model of the machine was developed. The FE model demonstrated a satisfactory correlation with the experimental data in terms of natural frequencies, even though it presented a strong limitation in terms of damping due to the lack of more in-depth test results. Nonetheless, it provided a significant reference in order to numerically characterize and finalize the TMD design (Chapter 2). In fact, even though the damping correlation was not representative, it allowed a reasoning by comparison for the results evaluation. One Flexible Multibody Model (FMM) was developed as well (Chapter 3). Also in this case, an adequate damping correlation was not found due to the scarcity of experimental evidence, nonetheless from the natural frequencies point of view the model exhibited an adequate correlation after a tuning activity. The FMM provided fundamental results, not only because it allowed an accurate reproduction of the machine trajectories taking into account the components flexibility, but also because it allowed a more accurate definition of the frequency content of the loads exchanged in correspondance of the machine joints. The loads exchanged in correspondence of the joints represented the boundary condition for the successive topology optimization of the components (Chapter 4). Therefore, it created the basis for an accurate topology optimization of the components. Additionally, during the tuning operations, both models allowed to evaluate some of the design choices previously made by the company and identify the machine critical points.

The TMD design is a well-established topic in literature, which is full of examples and optimization strategies. In the present work a simple design procedure was proposed as reference for future designs, useful especially for designers with no experience on the topic. Moreover, the TMD proved to be effective to damp in-plane oscillations independently of the angular orientation along the normal to the base plane. Furthermore, the TMD proved to be effective with a limited maximum mass ratio, i.e. 2% and offered tunability by the modularity of its design in a range between 16 Hz up to 24 Hz to compensate for machine variability. The added value of the proposed item stands in the utilization of its circular springs and the modularity of its design that allow a tunability by simple substitution or addition of simple components.

As for the design optimization strategies, two different weakly-coupled methods, Equivalent Static Loads (ESL) method and Quasi Static Loads method (QSL) were implemented and compared to evaluate pros and cons of both. To the best of the author's knowledge evidence of this comparison was not present in literature. Furthermore, the application of the ESL method resulted to be quite controversial, and the objective was also to identify its suitability for simple and practical cases. A modified version of the ESL method with respect to the one employed in literature was also proposed, foreseeing an intermediate Guyan reduction to properly identify the load application points during the optimization process, to reduce the topology optimization set-up time and to increase the design volume available for the optimization. Additionally, the optimization methodologies provided significant outputs for the re-design of some machine components and the consequent stiffening of the overall structure from a numerical point of view.

The most important contribution provided by the present Thesis, as indicated also in the concluding part (Chapter 5) is the bridging between the academic field, full of methodologies and examples, and the industrial one which often requires a practical adaptation of the latter due to the presence of more complex problems. From the industrial standpoint, the main outcomes consist in the proposal of simple design procedures and quantitative indications to tackle the dynamic design of machines. Furthermore, the modelling choices, tuning approaches and design comparisons may provide valuable lessons learnt and references for the development of finite element, multibody models or TMD design. From the academic standpoint a remarkable number of pertinent references was investigated. A historical development perspective was provided, especially for Chapters 2-3, an extended classification for dynamic damper was provided in Chapter 2 and a theoretical setting was presented in Chapters 3-4 in order to provide the reader the basics for the multibody dynamics and topology optimization. Furthermore, an alternative and novel design and characterization of a TMD is proposed. On top of that an updated procedure for ESL method optimization is proposed and compared to a different weakly-coupled method.