Load Assessment and Analysis of Impacts in Multibody Systems

Francisco González, József Kövecses

Department of Mechanical Engineering and Centre for Intelligent Machines
McGill University
817 Sherbrooke St. West, H3A 2K6 – Montréal, Québec, Canada
franglez@cim.mcgill.ca, jozsef.kovecses@mcgill.ca

Abstract

Impact dynamics is generally addressed in multibody systems using one of two approaches: 1) impulse/momentum level formulations and 2) penalty formulations or continuous force based methods. The main assumption for impulse-momentum level approaches is that the duration of impact is negligible on the time scale determined by the finite motion of the system. This makes it possible to integrate the dynamic equations and consider them at the impulse-momentum level. This, however, eliminates the contact forces from the formulation and includes only their impulse. This can be appropriate for various applications (e.g. for motion simulation). However, for many engineering applications, such as engineering design problems, more explicit knowledge about the contact loads and contact intensity is needed. A natural choice for a performance indicator to assess these loads is the contact forces developed. This requires the use of continuous force models. A significant number of such force models is available. These are often based on the assumption of Hertzian contact together with various representations for dissipation. However, continuous force models can result in high uncertainty for the contact forces, and can make reliable force estimation difficult for several reasons. All of these methods are highly dependent on the parameterization of the contact interfaces, e. g. stiffness, damping. The related parameters can be difficult to identify, and even if identified properly they are usually representative for one single setup only. As these parameters are usually associated with simplified contact models, their values depend on the global system properties so any change in those requires re-calibration.

Engineering design and decision making generally rely on the use of indicators to characterize the required system function and performance. We generally term such quantities *performance indicators*. Here we propose an alternative performance indicator to assess loads developed during impact and contact transition in general. This does not require a contact model and parameterization, but it can reflect the effect of the overall system properties and parameters on the impact loads. Our main concept for the performance indicator is that at the onset of the contact the geometry of the system determines the main directions to be constrained via the impact (e.g. normal directions). In turn, this makes it possible to decompose the dynamics of the system to constrained and admissible motions. This decomposition can be used together with both impulse-momentum and continuous force model based approaches. Our proposal is that the kinetic energy associated with the constrained motion at the beginning of the contact, T_c^-, can be used as performance indicator to characterize impact loads as an alternative to contact forces. The expectation from mathematical and mechanical modelling is essentially to provide performance indicators, both the concepts and the algorithms to determine them. For a performance indicator often the importance is not on its actual numerical value, but rather on the way how its behaviour reflects changes in system parameters or designs. For example, the value of our proposed performance indicator changes in the same way as the peak contact force developed during impact does. If we evaluate two different designs against each other for the same contact task, if T_c^- is greater for one of the designs then the peak impact force will also be greater for that case. This can help the designer to make a decision. This performance indicator is applicable to a large class of problems of direct engineering relevance.

A series of dynamic simulations were carried out to validate the above claims. The paper will include more detailed case studies and analytical results as well as experimental demonstration. Here we present some results for a double pendulum undergoing impact against a flat plane (Figure 1). This is an example frequently used in the literature for illustration of impact dynamics models and algorithms. Different impact configurations and velocities of the mechanism were studied. These can be seen here as the design

scenarios for the multibody impact system. The resultant contact forces were subsequently computed using several contact force models available in the literature [1, 2]. This included cases with and without friction along the tangential directions. The proposed performance indicator was always able to predict the load intensity during impact, i.e. if higher or lower contact forces were developed. Sample results are shown in Figure 2. The results showed that the maximum value of the normal contact force changes the same way as T_c^- does. On the other hand, the total system kinetic energy at the beginning of the impact, T^-, is not a valid performance indicator as its change is not following the peak contact force. For the non-ideal contact cases including energy dissipation, the value of T_c^- remained a valid indicator of the maximum normal contact force.

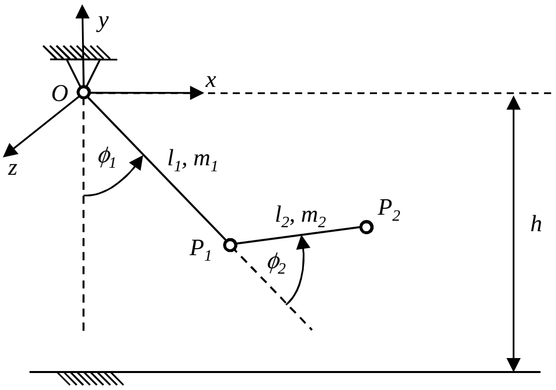

Figure 1: Model of a double pendulum used in this research.

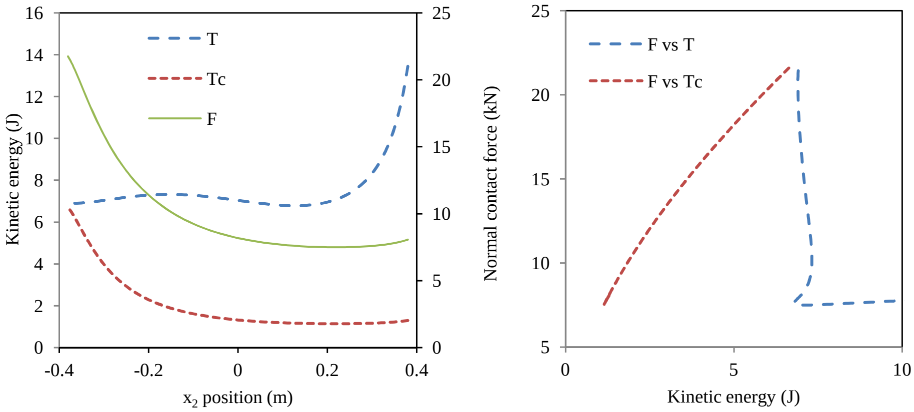

Figure 2: Total kinetic energy (T) and constrained motion space kinetic energy (Tc) at the beginning of impact, and maximum normal contact force (F) for different impact configurations of the mechanism (left); correlation between values of T^- and T_c^- and normal force (right). $\dot{x}_2 = 1$ m/s and $\dot{y}_2 = -1$ m/s. $\phi_2 > 0$.

References

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