Scalability study of particle method with dynamic load balancing in LS-DYNA®

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Abstract

We introduce an efficient load-balancing algorithm for particle blast method (PBM). Load-balancing is achieved by dynamically adaptively using RCB to evenly distribute workload to processors. Numerical tests demonstrated that with reformulated parallel scheme, the speedup for an airblast problem can be 20~30 times or more when using 128~192 cores.

Introduction to Particle Blast Method

Particle blast method (PBM) [1][2] is intend to model the gaseous behavior of high velocity, high temperature detonation products. PBM is developed based on corpuscular method (CPM), which has been successfully applied to airbag deployment simulation where the gas flow is slow. For blast simulation where gas flow is extremely high, the equilibrium assumption in CPM is no long valid. By reformulating the particle interaction algorithm, the PBM is capable of modelling blast loading that is typical thermally non-equilibrium system.

Since PBM was implemented in LS-DYNA in 2013, the accuracy of PBM have been demonstrated in [3][4]. Due to its simplicity and robust, this method is suitable for problems with complex geometry and boundaries. The Lagrangian nature allows non-diffusive advection. However, the performance of parallel code was not quite satisfactory. The PBM did not scale well when the total number of CPU is less than ~20. When more CPU are used, the speedup became saturated.

In this paper, we developed dynamic load-balancing algorithms for PBM. These are needed to handle millions or tens of millions of particles modeled in large distributed-memory computer systems. The basic idea is to control the domain partitioning to give each process an equal workload during the simulation run. Our method utilizes Recursive Coordinate Bisection (RCB) domain decomposition which recursively halves the model using the longest dimension of the input model. The imbalances in the execution time between parallel processes are monitored. Load-balancing is achieved by dynamically adaptively using RCB to make sure each process has equally workload.

Numerical Model: Air Blast Simulation

The experimental example is taken from [5] and has been studied in [2], where clamped square 3.4 mm thick AL-6XN plates are exposed to the blast loading from a spherical charge consisting of 150 g C-4. The charge was placed 150mm from the plate. The test apparatus allowed 613 mm square test plates to be fully edge-clamped using a cover plate and series of bolts. The region exposed to sand impulse was 406 mm x 406 mm. The region below the plate was hollow and shielded from the blast, enabling the target unrestricted deflection. (***Figure 1***).

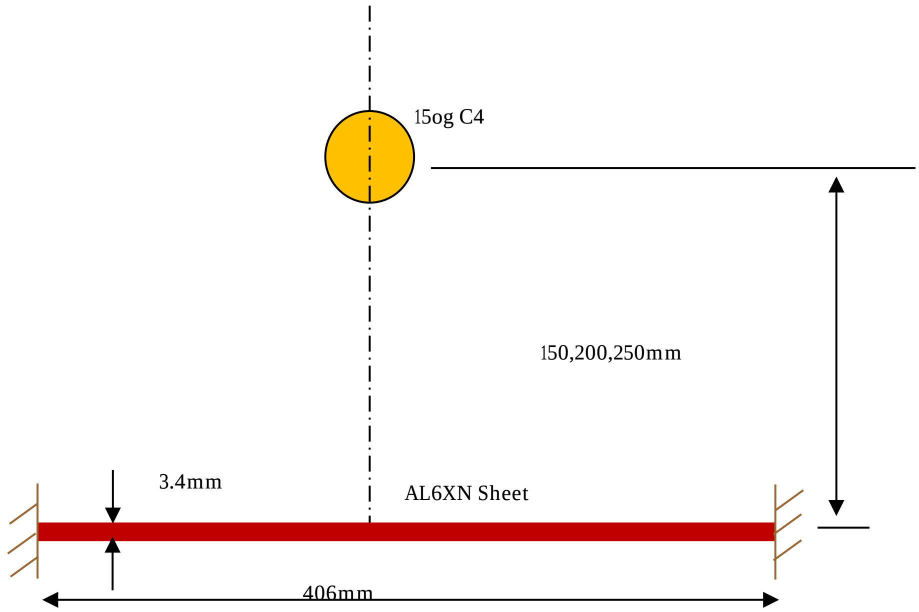

Figure 1 Sketch of the experimental set-up

The AL-6XN steel is a relatively new stainless steel with high strength, very good, and excellent corrosion resistance in chloride environments. The AL-6XN stainless steel material was modeled using a modified Johnson-Cook constitutive equation *MAT_MODIFIED_JOHNSON_COOK. The material parameters used in the simulation are adopted from [5] and listed in *Table 1*.

r (kg/m^3)	E(Gpa)	n	χ	C_p (J/kgK)	α(K^{-1})	$\dot{\varepsilon}_0$(S^{-1})
8060	195	0.3	0.9	500	1.5E-5	1.E-3
A(MPa)	B(MPa)	n	C	m	Tr(K)	Tm(K)
410	1902	0.82	0.024	1.03	296	1700

Table 1 Material properties of the AL-6XN stainless steel

A cross-section of the bare charge simulation model at different time is shown in ***Figure 1***. Free boundary conditions were used such that no reflections from the boundaries are present. The number of air particles is set such that air particle mass equal to C-4 particle mass. Simulations were conducted using (N_{he}; N_{air}) = (2,000,000; 1,700,000). The comparison between numerical results with experimental results has been performed in [2] and will not be discuss here.

Table 2 list the total CPU time comparison between R122420 with current approach that with dynamic rebalancing version (RB). It can be seen that for R122420 that without rebalancing, the performance for 12 processes is already saturated: more processes just mean more simulation time, the simulation time increase from 7 hours to ~10 hours when 192 processors are used. The current approach can scale up to nearly 200 processes. Furthermore, the total CPU time is greatly reduced: with 12 processes, the CPU time is reduced from 7 hours to 1 hour 22 minute, more than 5 times speedup is obtained. The speedup increase with more processes. For the case with 192 processes, almost 30 time speedup is obtained, the total CPU time is reduced from ~10 hours to ~20 minutes.

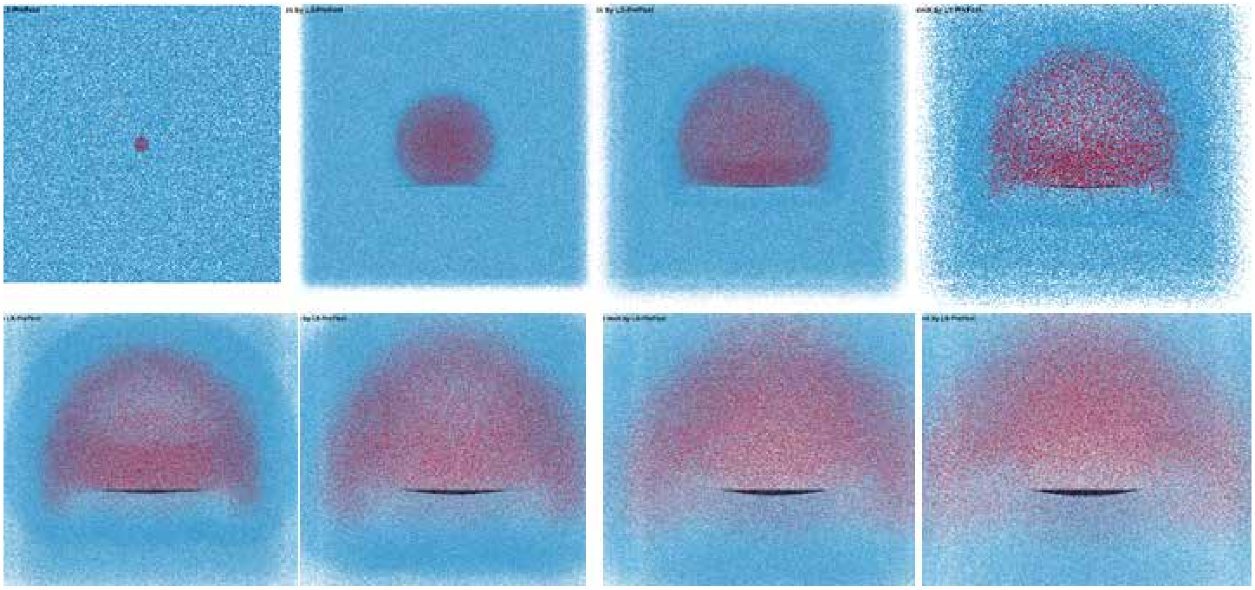

Figure 2 PBM simulation with (200000:1700000) after detonation

#of CPUs	Total CPU time(s)		
	SVN 122420	RB	Speedup
12	25190(7h0m)	4916(1h22m)	5.12
24	24681(6h51m)	3188(53m)	7.77
48	26540(7h22m)	2168(36m)	12.24
96	30719(8h32m)	1482(25m)	20.73
192	35627(9h54m)	1217(20m)	29.27

Table 2 Total CPU time

#of CPUs	Particle to Particle Contact time(s)		
	SVN 122420	RB	Speedup
12	15506	2596	5.97
24	15809	1411.2	11.20
48	17183	739.7	23.23
96	19912	394.9	50.42
192	22468	239.1	93.97

Table 3 Particle-Particle Contact time

#of CPUs	Particle to Structure C time(s)		
	SVN 122420	RB	Speedup
12	4982.6	1714.1	2.91
24	4742.3	1350.7	3.51
48	5118.1	1127.5	4.54
96	6585.0	849.2	7.75
192	8863.7	731.9	12.11

Table 4 Particle-Structure Contact time

Table 3 and Table 4 list the CPU time for particle-particle contact and particle-structure contact. Particle-particle contact clearly achieve much better scalability. With 192 processors, nearly 2 order of speedup is obtained for particle-particle contact compared to R122420. The CPU time spent on particle-particle contact is reduced from more than 6 hours (22468s) to less than 4 minutes (239.1s). The speedup for particle-structure contact time is not as good as particle-particle contact, due to the fact that particle and structure are decomposed separately, but still get ~12 time for 192 processors.

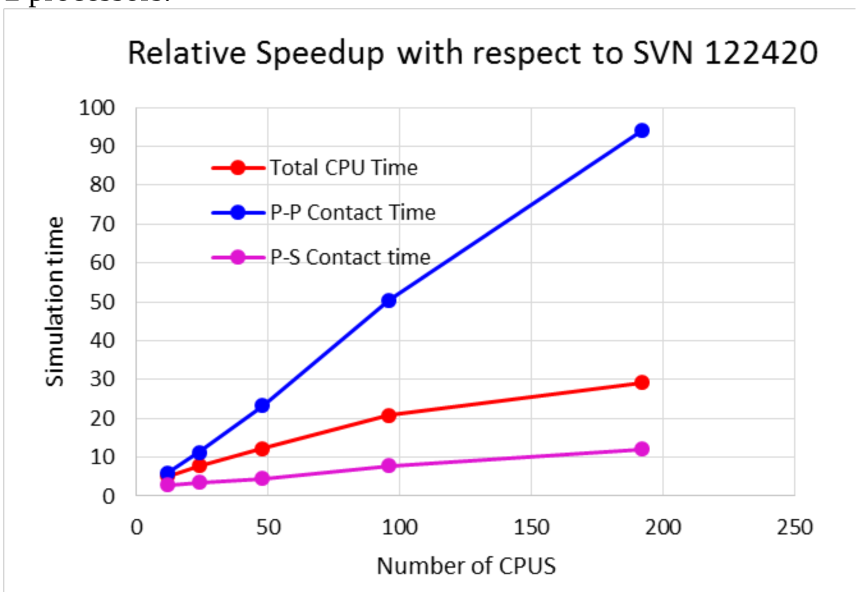

Figure 3 Relative Speedup with respect to SVN 122420

The relative speedup curve for total CPU time, particle-particle contact, and particle-structure contact is shown in ***Figure 3***.

Summary

We introduce dynamic load balancing approach for particle blast method (PBM). By applying a Recursive Coordinate Bisection (RCB) domain decomposition scheme, a minimization of communication expense and evenly distributed workload can be achieved. Numerical test demonstrate the efficiency of the approach.

References

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