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Simulation based optimization of forage harvesters

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Forage harvesters are used worldwide to harvest grass, corn or hay. After the crop has been chopped into small pieces it's accelerated and thrown, via a spout, into a tractor-driven trailer. The interaction between crop and air flow plays an important role in the spout. The design of the spout determines how well it can handle crop in different harvesting conditions. When the trailer is full the tractor takes the crop to storage silos and bunkers where it is compacted and fermented to provide feed for livestock or biomass used for bioenergy.

Designing spouts is not a trivial task as this component needs to operate optimally for different crop types, in different harvesting conditions and for different, operator chosen, machine settings. Moreover, the time for physical testing is limited to the harvesting window (a limited number of weeks per year). For these reasons computer simulations are used frequently nowadays when developing agricultural machines. The interaction of the crop flow with functional components is typically simulated using discrete element modelling (DEM), the air flow is taking into account using computational fluid dynamics (CFD).

Prior to this research, a simulation model of the crop flow through the functional channel of a forage harvester has been developed and successfully validated using field test data. In the current research that simulation model was used to determine the optimal spout's curvature. Seven parameters (some correlated, some with restrictions between them) were identified determining the spout shape. Next to these geometrical parameters also crop properties and machine settings were taken into consideration (e.g. the crop throughput (tons/h), the length of cut (LOC), the engine RPM (determining the rotational speed of all functional machine components and therefore also the speed of the crop), the spout height and rotation setting, etc.).

Although, simulations are considerably cheaper than building prototypes and testing those in field conditions, coupled DEM-CFD simulations still come at a high computational price (calculation times range from a couple of days to a couple of weeks depending on the required accuracy and the number of particles). To maximize the information gained from a limited number of simulations a designed test plan was used (space filling design). In total 130 simulations were performed with different combinations of spout shapes, crop properties and machine settings. Gaussian processes were used to link the simulation output (spout efficiency, crop speeds, risk of blockages) to these test plan parameters. Once these surrogate models were available, they were used to find optimal spout shapes. For this, a second space filling design was used to evaluate the performance of 20000 spout shapes (taking the restrictions into account). A desirability function (considering all output variables) was used to evaluate the different spout designs. The pareto front provided the most interesting spout shapes.

A modular spout, where the shape can be adjusted on the go, was used to evaluate the most promising designs in field conditions.

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