Discussion Paper

Electrical Drive Design with the Digital Twin

Standardised Submodel of the Asset Administration Shell

Verband der Elektro- und Digitalindustrie

Content

Management-Summary

Representatives from mechanical engineering and the process industry as well as the fields of classification and standardisation have joined forces in a ZVEI working group to drive forward the realization of "Drive 4.0" with the cooperation of university research.

This discussion paper now presents the results achieved in more detail and explains the implementation of the electric drive as an Industrie 4.0 component during the design and configuration phase.

The optimal design of an electric drive is used to find a compact drive or drive system that is optimally designed in terms of speed, torque, positioning accuracy and efficiency, which is not only lighter, but also performs better and saves energy.

With the standardised digital twin, the Asset Administration Shell, and the possibility of standardised submodels, the data exchange in drive design can be kept efficient, interoperable and up-to-date.
The proposed submodel template specification addresses machine and plant manufacturers, manufacturers of drive compontents and developer of sizing tools that exchange information for the use case of drive design. The objective of the drive design is to select suitable components based on movement patterns and system requirements. The submodel itself can be assigned to a design project, a drive axis or even individual components of a drive system.
Major components that are described:

- **Sizing Project:** Identifying characteristics of the sizing project with reference to the sizing project file.
- **Customer Requirements:**
  - **Motion and load profile:** The specified motion sequence and the calculated motion, taking into account the workload and customer specifications.
  - **Environmental:** Environmental conditions in which the drive train is to be operated.
  - **System Requirements:** The features required by the customer in the selection of individual components and in the consideration of the overall system.
- **Transformation mechanisms:** Mechanisms for transmitting the force in the drive task, such as belt or rack and pinion applications.
- **Sizing Results:**
  - **Bill of Material:** Simple list for ordering the individual components.
  - **Utilization Rates:** Technical data of the drive components and their utilization rates in relation to the requirements in the motion profile.

1 Motivation: Benefits for manufacturer, machine builder and operators

Electric drives are increasingly used in environments where production processes are becoming more and more high-tech and customer specific. Also, the focus on sustainability and preserving the environment for future generations is now also crucial in developing the next generation of production systems. The optimal design of an electric drive is used to find a compact drive or drive system that is optimally designed in terms of speed, torque, positioning accuracy and efficiency, which is not only lighter, but also performs better and saves energy. The ZVEI publication Energy Efficiency with Electric Drives[1] already shows how great the savings potential is in mechanical system optimisation.

Potential savings from electrically driven systems	Potential savings in %
1. Increased use of energy-efficient motors	10
2. Electronic speed control	30
3. Mechanical system optimisation	60
Total	**100**

Source: Save reports from the EU

For the optimum design of an electric drive system, the application data must first be determined. This is used to calculate the individual components of the entire drive train consisting of the mechanics and the electric drive are calculated. When selecting a suitable drive, both the maximum forces and speeds and the values that are decisive for the required service life must be taken into account. The limit values specified by component supplier and imported in the sizing tools must not be exceeded. Modern sizing tools support both manufacturers and machine builders in the task of selecting the most suitable drive components. Data import is usually based on proprietary import formats and manual input, which leads to high effort and possibly outdated data. With the standardised digital twin, the Asset Administration Shell, and the possibility of standardised submodels, this data exchange in drive design can be kept efficient, interoperable and up to date.

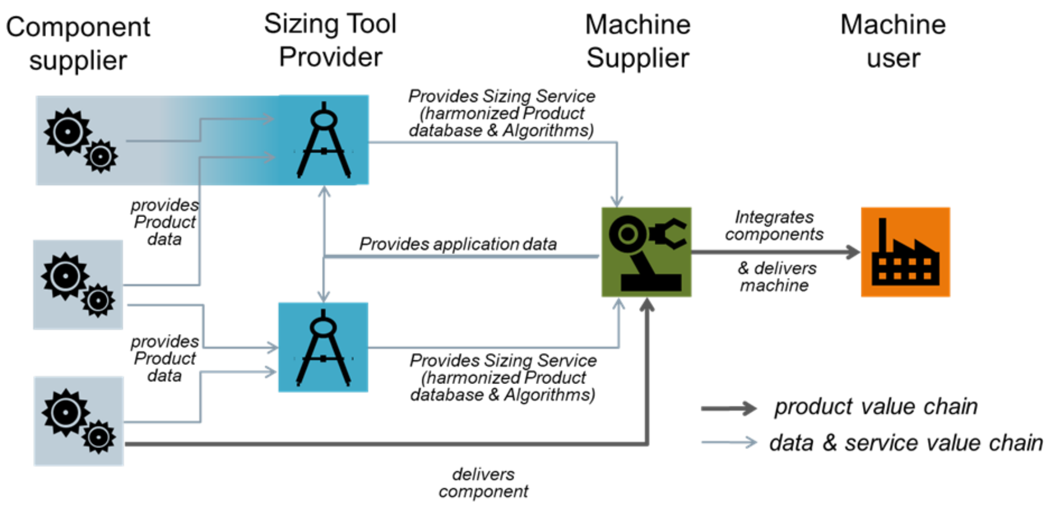


Figure 1 Business View of Drive Configuration (Source: ZVEI)

[1] Energy Efficiency with Electric Drives
https://www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Publikationen/2017/November/Energieeffizienz_mit_elektrischen_Antrieben/ZVEI_BR_Energieeffizienz_Antriebe_NEU6.12.17_DOWNLOAD.pdf

2 Submodel Template: Exchange of sizing information for power drive trains

2.1 Scope

The submodel template aims at interoperable provision of information, especially information for sizing electrical drive systems in industrial automation. For this purpose, the essential components drive, motor, gearbox, transformation as well as their additional components are described and the parameters necessary for the calculation are considered. Mechanical and electrical aspects are considered in the drive design. The submodel specification addresses machine and plant manufacturers, manufacturers of drive compontents and developer of sizing tools that exchange information for the use case of drive design. This submodel complements the specifications of Automation ML2. The objective of the drive design is to select suitable components based on movement patterns and system requirements.

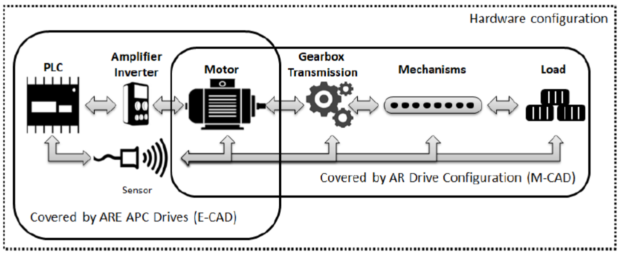
2.2 Approach

The submodel template draft was created by the ZVEI working group "Industrie 4.0 Drive Technology" and AutomationML e.V. For this template, the sizing tools of different providers and their data formats were compared. From this, cross-vendor characteristics were derived. In addition, the existing Automation ML and AAS submodels were examined and evaluated for use in the context of data exchange in the sizing process.
Three aspects were identified:

- Extension of the AAS submodel template "Generic Frame for Technical Data for Industrial Equipment in Manufacturing"3 to include the required technical component data for the sizing process.
- The information and sizing results provided in the Automation ML drive configuration project should be made available in the usage phase of an asset.
- Definition of cross-vendor system requirements and motion sequences which have to be fulfilled from the user’s point of view.

2.2.1 AutomationML Application Recommendation for Drive Configuration

The data exchange format AutomationML which is standardising in the IEC 62714 standard is a neutral, free, and XML-based data format. It has been developed in order to support the data exchange between engineering tools in a heterogeneous engineering tool landscape. As AutomationML is the leading format for data exchange in the engineering phase and AAS to be seen as the medium to transport data across different phases of the lifecycle, the existing AutomationML model shall be used and integrated into the AAS. With this only data required in other phases than enginnering shall be “published” in the AAS. All other data can remain in the AutomationML file. There are three options to integrate the AutomationML model in the AAS. The here described approach is general and can be applied to any models. Here specificly for the power train.



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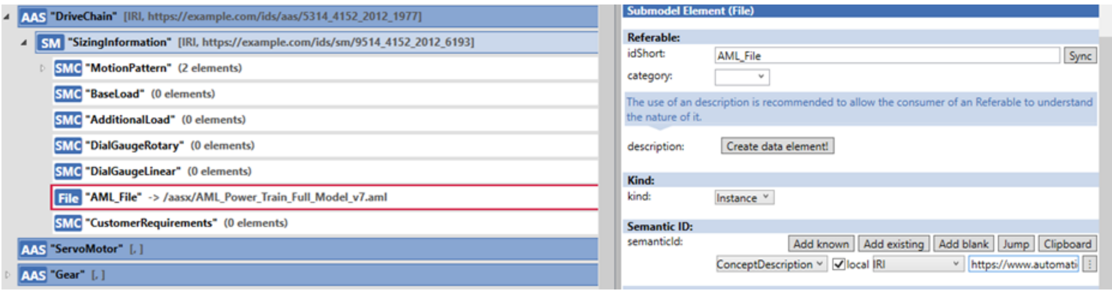
[2] AR – Drive Configurations (M-CAD aspects): https://www.automationml.org/wp-content/uploads/2021/06/AR-Drive-Configurations-v1_0_0.zip

[3] IDTA AAS Submodels; https://industrialdigitaltwin.org/en/content-hub/submodels

Referencing the complete Automation ML file

From the submodel simply a reference to the complete AutomationML file is made. In this case the AAS contains basically only the information about the existence of the submodel “Sizing”, additional meta information and the file reference.

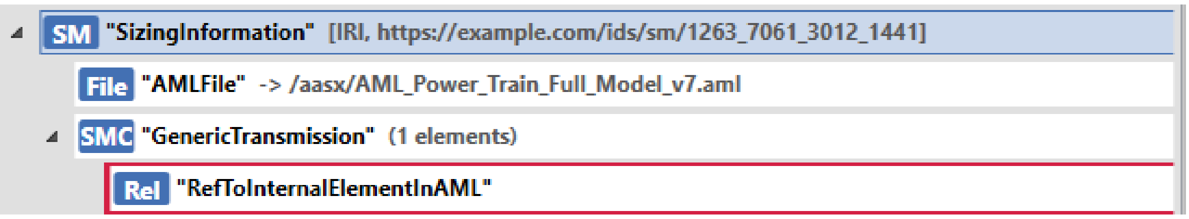
In the AAS the submodel element “File” with semantic id (IRI; https://www.automationML.org/file) can be used.

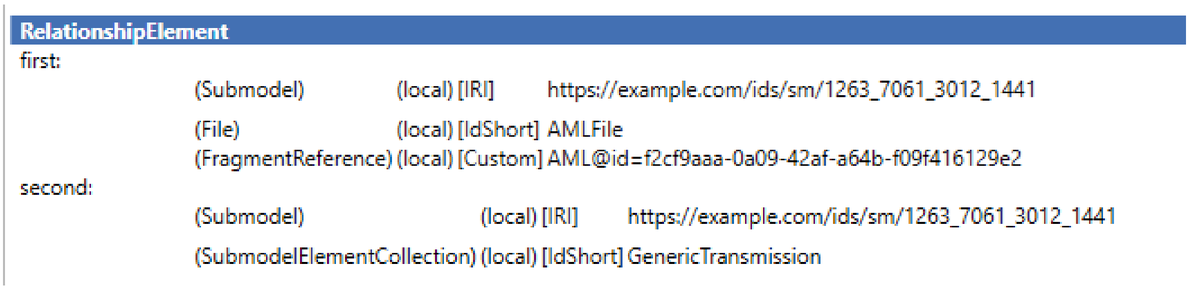


Referencing to specific entries in the AutomationML file

In this case additional information of the AutomationML model shall be published in the AAS. Here again the AAS basically provides the information on the existence of that information and reference into the AutomationML to the location where this information can be found. In that case a tool must be able to understand AutomationML and it may get from the AAS the information about what data exactly shall be read.

In the AAS submodel this is realized by a “RelationshipElement”. This element consists of two parts. One side points into the AutomationML file. The other points to the submodel element in the AAS.





The first item points to the FileReference of the AutomationML file and uses a FragementReference to point into the AutomationML file.

Since AutomationML uses unique GUIDs those can be used in the reference. In the case here the Relationship Element points to an internal Element.

The Fragment Reference looks as following: AML@id=f2cf9aaa-0a09-42af-a64b-f09f416129e2
The second part points to the submodel element that represents that information in the AAS. Here the semantic id of the element shall be the corresponding role of the AutomationML model that the InternalElement is using.

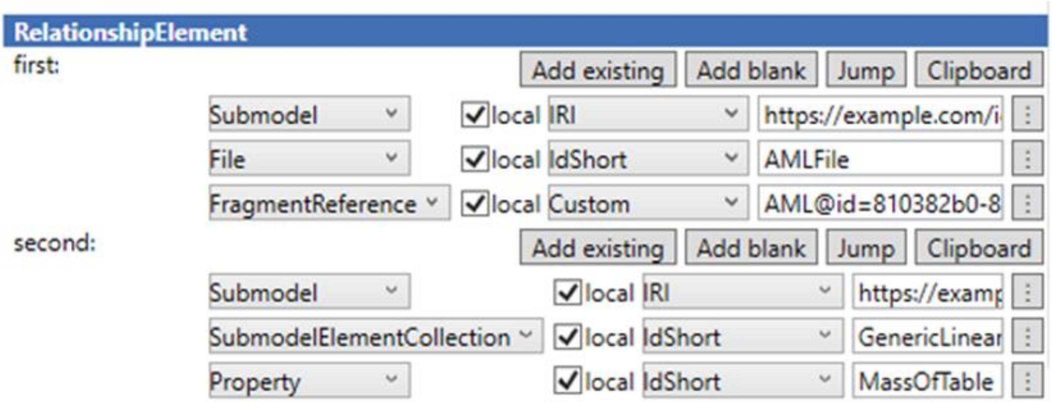
In the example above this would be: https://www.automationml.org/semantic/DriveConfigurationRoleClassLib/1/0/0/AbstractTransmission/GenericTransmission

Here it is necessary to define a mechanism to convert AutomationML role and interface class libraries into concept descriptions.

Publishing certain values from the AutomationML file
In this case additionally values from the AutomationML model shall be published into the AAS. The selection of the values shall be done carefully since information will be duplicated and changes need to be handled to prevent inconsistencies.

The lead shall be always the AutomationML model. The AAS points to an attribute in the AutomationML model in order to publish its value.

In this case a tool that is not able to read AutomationML data can still read some information directly from the AAS submodel.



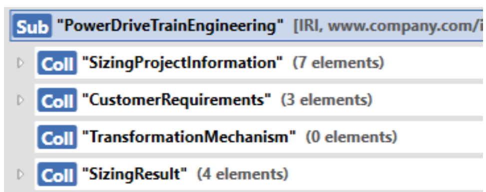
The reference here will be done as well with a RelationshipElement. Again using the first part to point to the AutomationML file reference and the FragmentReference to point into the file. Since in AutomationML attributes are identified by their name with the element this shall be done here in the same way.

FragementID = AML@id=810382b0-8c4b-4df2-a0f5-6bfa0dc26908.MassOfTable

With the id being the GUID of the InternalElement followed by "." and the name of the attribute. For the property itself the semantic id that represents the AutomationML semantic shall be used. In the example above this would be the following:
https://www.automationml.org/semantic/DriveConfigurationRoleClassLib/1/0/0/AbstractLoadMechanism/BallScrew/MassOfTable

2.3 Definitions

The PowerDriveTrainEngineering submodel consists of four structuring sections that are populated during the design process. The submodel itself can be assigned to a design project, a drive axis, or even individual components of a drive system.



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- **Customer Requirements:**

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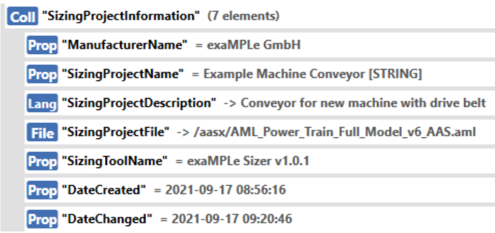
- **Environmental:** Environmental conditions in which the drive train is to be operated.
- **System Requirements:** The features required by the customer in the selection of individual components and in the consideration of the overall system.

- **Transformation mechanisms:** Mechanisms for transmitting the force in the drive task, such as belt or rack and pinion applications.
- **SizingResult:**
  - **Bill of Material:** Simple list for ordering the individual components.
  - **Utilization Rates:** Technical data of the drive components and their utilization rates in relation to the requirements in the motion profile.

2.3.1 Sizing Project Information

The general information provides an overview of the sizing project. The sizing project file with the reference to the sizing tool and the creation and modification timestamps can also be included in the asset administration shell.

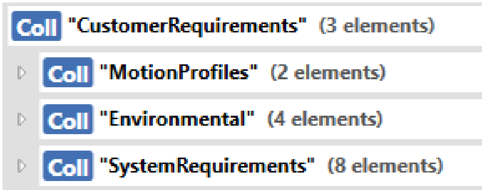


Notice - the sizing project may be in a proprietary data format. Preferred standard for the engineering phase is the Automation ML File Format.

Notice - Further information, such as the contact details of the persons involved in the design or approval workflows are feasible.

2.3.2 Customer Requirements

The customer requirements section contains the customer's specifications for the drive task. Customer requirements are divided into the sections motion profile, environmental conditions and system requirements.



2.3.3 Motion Profiles

The basis for selecting the optimal drive system is the motion and load profile that needs to be met. The motion profile consists of individual motion segments that specify the travel distance, the travel time and the forces.

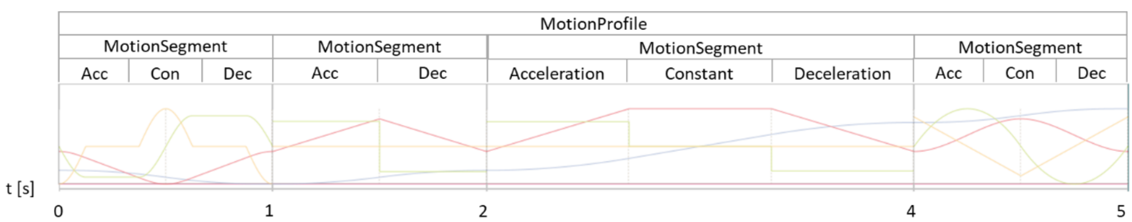
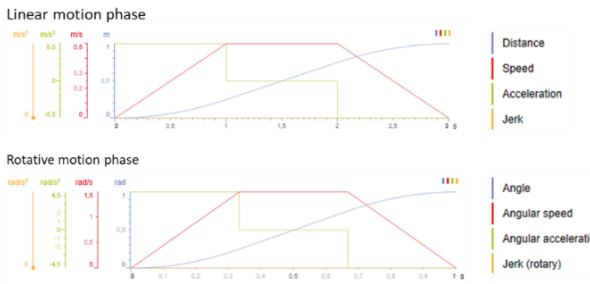


Figure 2 Motion Profile and Segments

Motion profiles are differentiated by linear and rotative motion and can be described using position or motion time specifications, shown in the table of Figure as option A and option B.



Linear Motion (Translation)		Rotative Motion (Rotation)	
Option A	**Option B**	**Option A**	**Option B**
Time [s]	TimeDuration [s]	Time [s]	TimeDuration [s]
Position [m]	DistancePointToPoint [m]	AngularPosition [rad]	TraverseAngle [rad]
Velocity [m/s]	RampForm AccelerationTime [s] ConstantSpeedTime [s] DecelerationTime [s]	AngularSpeed [rad/s]	RampForm AccelerationTime [s] ConstantSpeedTime [s] DecelerationTime [s]
Acceleration [m/s²]		AngularAcceleration [rad/s²]	
Jerk [m/s³]	Jerk [m/s³]	AngularJerk [rad/s³]	AngularJerk [rad/s³]
LoadMass [kg]	LoadMass [kg]	MomentOfInertiaOfLoad [kg m²]	MomentOfInertiaOfLoad [kg m²]
LoadSideForce [N]	LoadSideForce [N]	LoadTorque [Nm]	LoadTorque [Nm]
		AxialForce [N]	AxialForce [N]
		RadialForce [N]	RadialForce [N]

Figure 3 Rotative and Linear Motion Segments

The time specification in option A always refers to the start time of the motion profile, whereas option B is a sequence of incremental time durations.

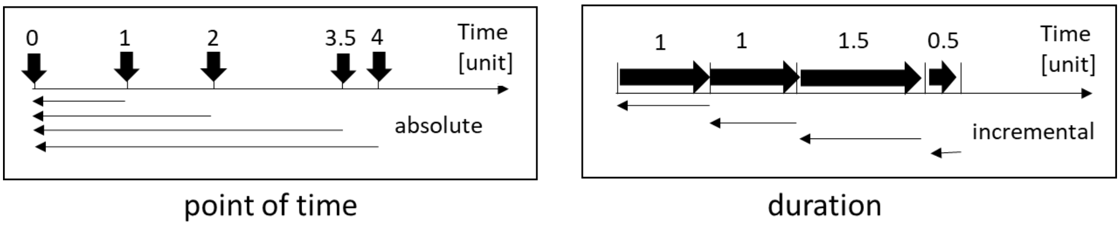


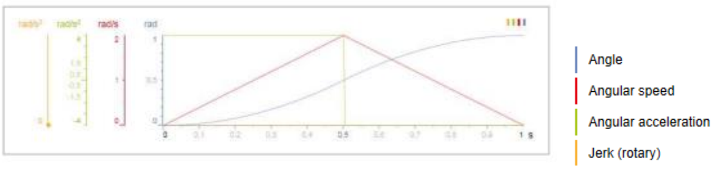
Figure 4 Difference of time points (Option A) and durations (Option B)

Motion Rules within a motion segment

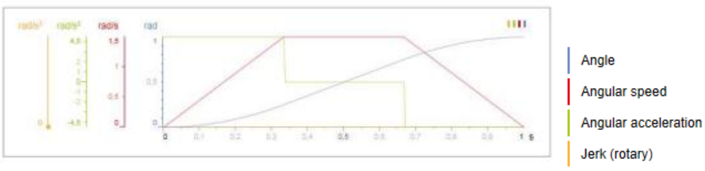
If the motion segments are specified in time durations (option B), a motion rule is also required as to how to travel within the segment. The ramp form refers to the motion rules, which are standardised in VDI 2143-1. VDI 2143-1 („Bewegungsgesetze für Kurvengetriebe; Theoretische Grundlagen“) is expected to be published in mid-2022 under the new title: "Bewegungsgesetze für Kurvengetriebe und Motion-Control-Systeme - Theoretische Grundlagen". In the new VDI 2143-1, rarely used profiles are supplemented by common profiles, e.g. a general modified acceleration trapezoid or the double S-profile for RR movements. A list of the current motion rules is shown in Table 1 and can be extended by manufacturer-specific rules of motion.

Linear
Linear motion rule, consisting of a straight line between acceleration, constant motion and deceleration

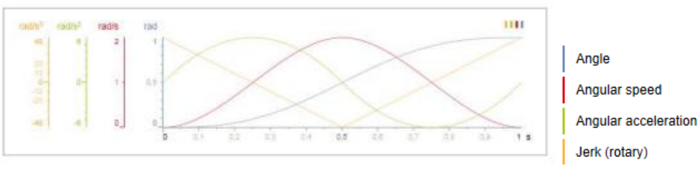
Triangle (1/2 Rule)
Linear motion rule, each consisting of acceleration and deceleration 1/2 of the total time



Trapeze (1/3 Rule)
Linear motion rule, each consisting of acceleration, constant travel and deceleration for 1/3 of the total time



4th order polynomial
motion rule where the velocity follows a 4th order polynomial



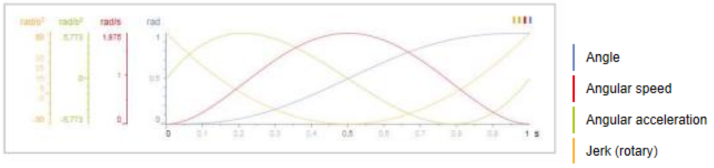
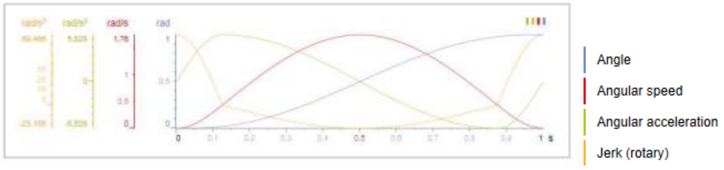
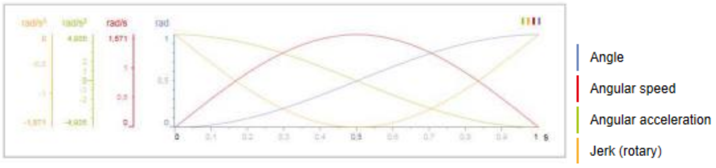
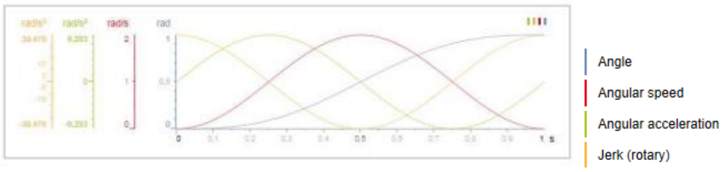
5th order polynomial motion rule in which the velocity follows a 5th order polynomial	
Modified trapezoid motion rule in which the velocity follows a modified trapezoid	
Modified sine Motion rule in which the velocity follows the function of a modified sine wave	
Sinoid motion rule in which the velocity follows the function of a sinoid	
Sine motion rule in which the velocity follows the function of a displaced, pure sine	

Table 1 Motion Rules

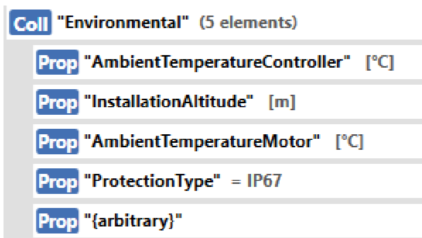
When fulfilling the drive task, limit values can be defined in addition to the motion and load curves, which must be complied with.

Linear Motion (Translation)	Rotative Motion (Rotation)
MaxSpeed [m/s]	MaxAngularSpeed [rad/s]
MaxAcceleration [m/s²]	MaxAngularAcceleration [rad/s²]
MaxJerk [m/s³]	MaxAngularJerk [rad/s³]
MaxPositionTolerance [m]	MaxAngleTolerance [rad]
PositionResolution [m]	AngularResolution [rad]

Table 2 Restrictions in the movement sequence

2.3.4 Environmental

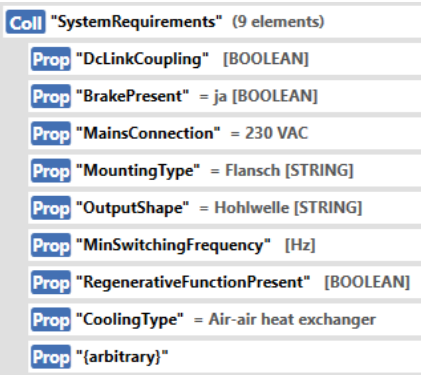
The section of the environmental conditions contains all requirements for the drive system, which are based on the operating conditions. In addition to the properties defined in this specification, further properties can be added by the User.



2.3.5 System Requirements

The system requirements refer to the characteristics of the drive system, in particular its interfaces to the power supply, mechanical integration or cooling. In addition to the properties defined in this specification, further properties can be added by the User.

Notice - The current design assumes a single axis. for multiple axes, the system requirements, if different, would also need to be described multiple times.

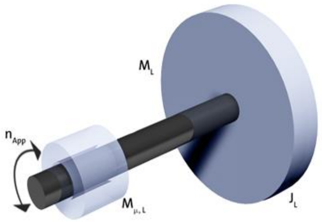


2.3.6 Transformation mechanisms

A transformation mechanism (application) is used, for example, to generate linear output motions through rotational drive motions. For the optimum design of the drive system, data of the application must be determined. The working group compared some common mechanisms from different sizing tools. More mechanisms will follow. The descriptive characteristics also represent the common denominator for a basic interpretation. Vendor specific extensions through additional properties are given.

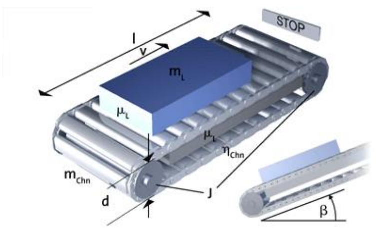
General Rotary Application

Parameter	Name	Symbol	Unit
Inertia	Moment of inertia of load	J_L	kgm²
TorqueFriction	Friction torque of load	$M_{\mu,L}$	Nm



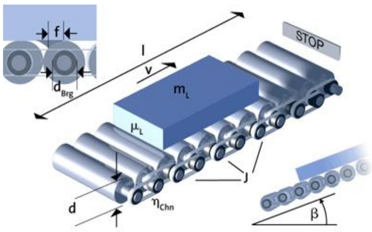
Chain Conveyor Application

Parameter	Name	Symbol	Unit
MassChain	Mass of chain	m_{Chn}	kg
DiameterDrivingRoll	Diameter of drive roll	d	mm
AngleTilt	Angle of tilt	β	rad
CoefficientFriction ChainBearing	Coefficient of friction chain/bearing	μ_{Gdn}	
InertiaRollers	Moment of inertia of rollers	J_{sum}	kgm²
EfficiencyChain	Efficiency of chain	η_{Chn}	
ForceAdditional	Additional force	F_{add}	N



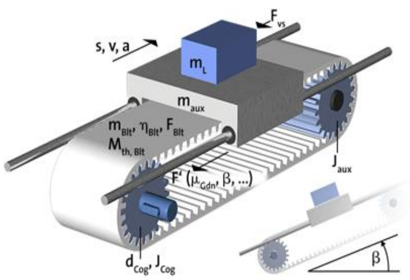
Roller Conveyor Application

Parameter	Name	Symbol	Unit
DiameterTransport Roll	Diameter of transport rollers	d	mm
DiameterBearing	Diameter of bearing	d_{Brg}	mm
CoefficientFriction Bearing	Coefficient of friction of bearing	μ_{Brg}	
LeverageRolling Friction	Leverage of rolling friction	f	mm
EfficiencyChain	Efficiency of chain	η_{Chn}	
NumberChainTurns	Number of wrapped chain turns	N_{Chn}	
AngleTilt	Angle of tilt	β	°
InertiaRollers	Moment of inertia of transport rollers	J	kgm²
ForceAdditional	Additional force	F_{add}	N



Belt Drive Application

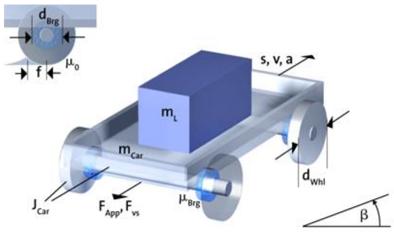
Parameter	Name	Symbol	Unit
DiameterBeltPulley	Diameter of belt pulley	d_{Cog}	mm
MassSlide	Mass of slide	m_{aux}	kg
MassBelt	Mass of toothed belt	m_{Blt}	kg
AngleTilt	Angle of tilt	β	°
TravelingResistance	Specific traveling resistance	F'	N/kg
EfficiencyBelt	Transmission efficiency of toothed belt	η_{Blt}	
InertiaBeltPulley	Moment of inertia of belt pulley	J_{Cog}	kgm²
InertiaDeflectionPulley	Moment of inertia of deflection pulley	J_{aux}	kgm²
DiameterBeltPulley	Diameter of belt pulley	d_{Cog}	mm



Traveling Drive Application (Cart)

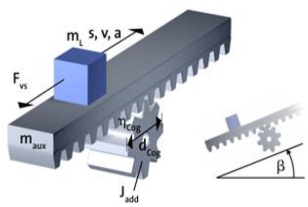
Parameter	Name	Symbol	Unit
DiameterWheel	Diameter of wheel	d_{Whl}	mm
MassVehicle	Mass of vehicle	m_{Car}	kg
TravelingResistance	Specific traveling resistance	F'	N/t

Gravitational acceleration	Gravitational acceleration	g	m/s2
LeverArmRollingFriction	Lever arm of the rolling friction	f	mm
BearingDiameter	Bearing diameter	dBrg	mm
FrictionCoefficient	Friction coefficient	μ	
SideFriction	Side friction	c	
AngleTilt	Angle of tilt	β	°
InertiaAdditional	Additional moment of inertia	J_{add}	kgm²



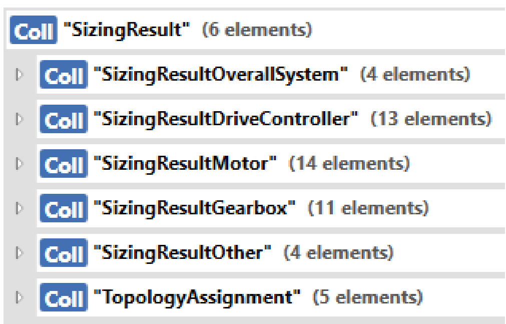
Rack Drive Application

Parameter	Name	Symbol	Unit
DiameterPinion	Diameter of pinion	d_{Cog}	mm
MassRackPinion	Mass of rack and pinion	m_{aux}	kg
AngleTilt	Angle of tilt	β	°
CoefficientFriction GuideRail	Coefficient of friction of guide rail	μGdn	
EfficiencyRackPinion	Efficiency of rack/pinion	η_{Cog}	
HelixAngle	Helix angle of the toothing		°
InertiaAdditional	Additional moment of inertia	J_{add}	kgm²



2.3.7 Sizing Result

The sizing results section contains the result data related to the overall system and the individual components. In particular, the specification shows the sizing results of the overall system and the relevant individual components (such as drive, motor, gearbox). Further components, such as add-on parts and accessories, can be inserted in the "SizingResultOther" section. The TopologyAssignment section represents the relationships between the components. For this purpose Relationship-Eements are specified, which arrange the components to each other.



Notice - The AutomationML file for the design project contains a complete list of relationships. In the AAS submodel, only the mechanical attachment is to be represented.

2.3.7.1 Overall System Sizing Results

2.3.7.2 Drive Sizing Results

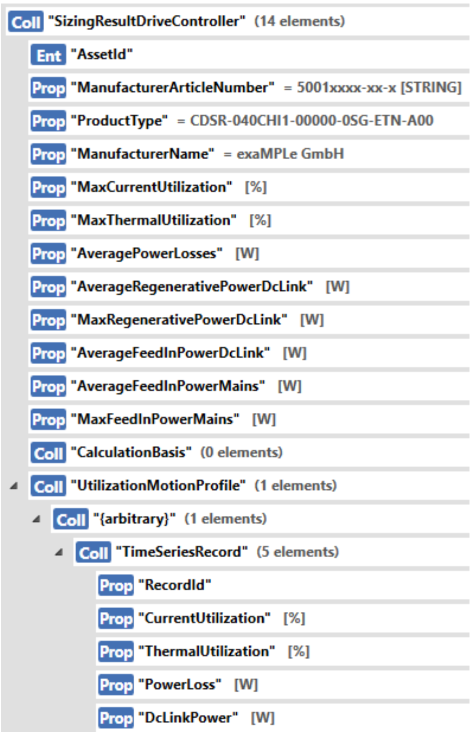
The sizing results of the drive consist of general information about the construction type and the order number.

Maximum loads and utilization over the entire motion profile and power losses are shown.

The CalculationBasis section is optional. The relevant technical data of the drive can be reported here.

For a more detailed view of the utilization and power losses, the Motion Profile can be copied from the customer specifications in the UtilizationMotionProfile section and supplemented with the performance data of the drive.

Notice - A copy of the motion profile may be beneficial for access control reasons or further use of the data.



2.3.7.3 Motor Sizing Results

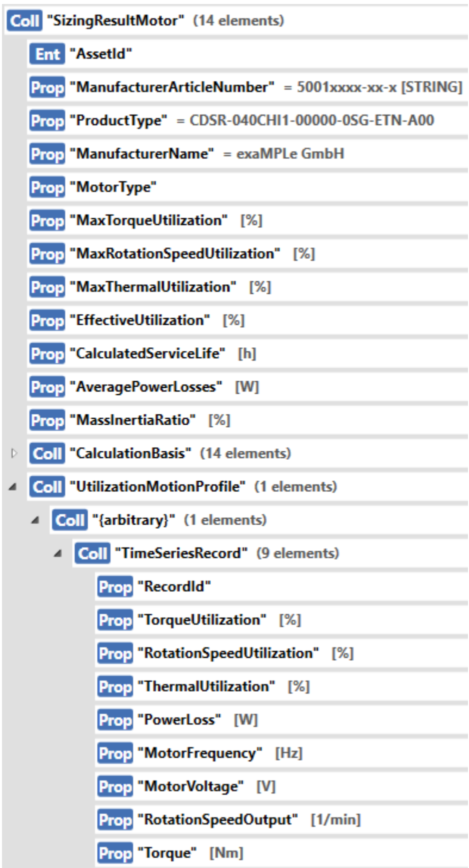
The sizing results of the motor consist of general information about the construction type and the order number.

Maximum loads and utilization over the entire motion profile and power losses are shown.

The CalculationBasis section is optional. The relevant technical data of the motor can be reported here.

For a more detailed view of the utilization and power losses, the Motion Profile can be copied from the customer specifications in the UtilizationMotionProfile section and supplemented with the performance data of the drive.

Notice - A copy of the motion profile may be beneficial for access control reasons or further use of the data.



2.3.7.4 Gearbox Sizing Results

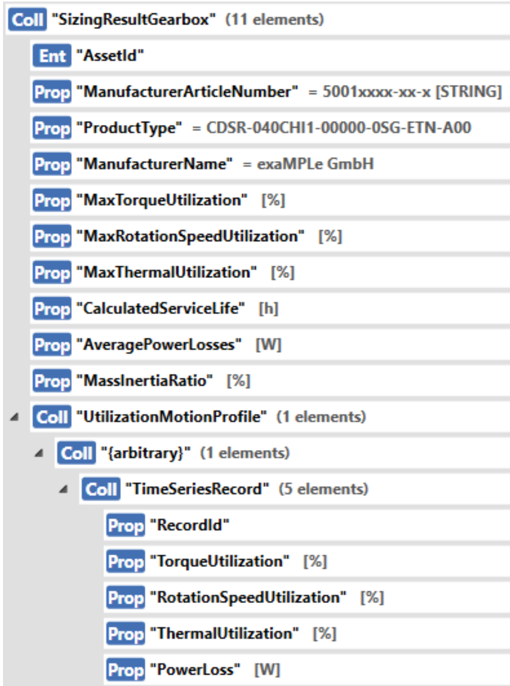
The sizing results of the gearbox consist of general information about the construction type and the order number.

Maximum loads and utilization over the entire motion profile and power losses are shown.

The CalculationBasis section is optional. The relevant technical data of the drive can be reported here.

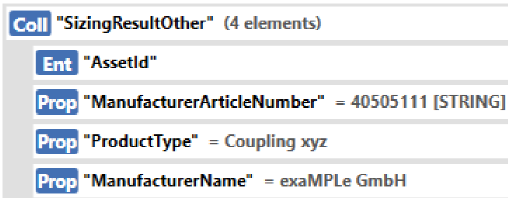
For a more detailed view of the utilization and power losses, the Motion Profile can be copied from the customer specifications in the UtilizationMotionProfile section and supplemented with the performance data of the drive.

Notice - A copy of the motion profile may be beneficial for access control reasons or further use of the data.



2.3.7.5 Other Sizing Results

The sizing results of other components, such as add-on parts and accessories, consist of general information about the product type and the order number.



2.3.7.6 Topology Assignment

The TopologyAssignment section represents the relationships between the components. For this purpose Relationship-Eements are specified, which arrange the components to each other.

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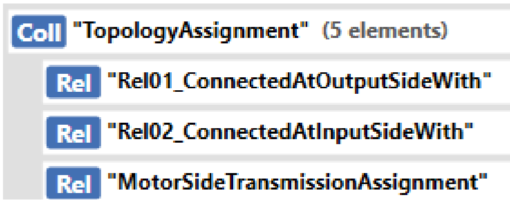

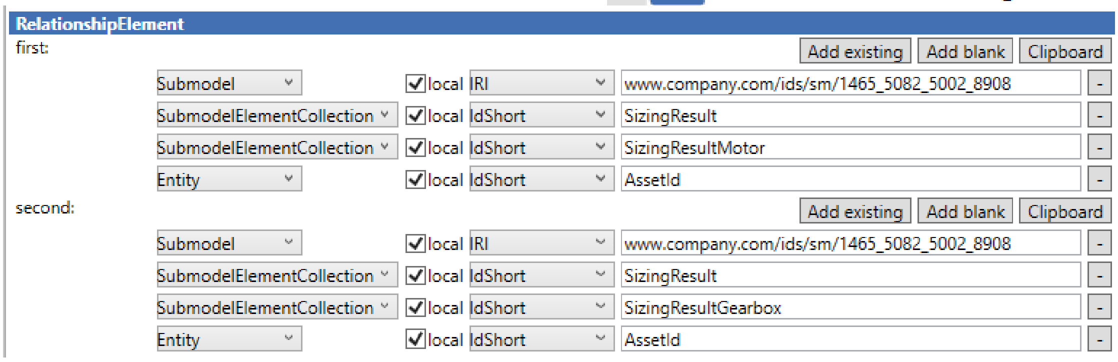

2.3.8 Technical Data of Drive Components

For drive sizing, it is necessary to know the technical data of the following individual components: Drive, Motor, Gearbox, Attachment parts such as couplings. The working group therefore specifies a collection for the component data, which can be provided both in the sizing project and in advance by the component manufacturers in the technical data submodel. During the sizing process, the manufacturer's data can be referenced or a copy of the data can be integrated into the PowerDriveTrainEngineering submodel.

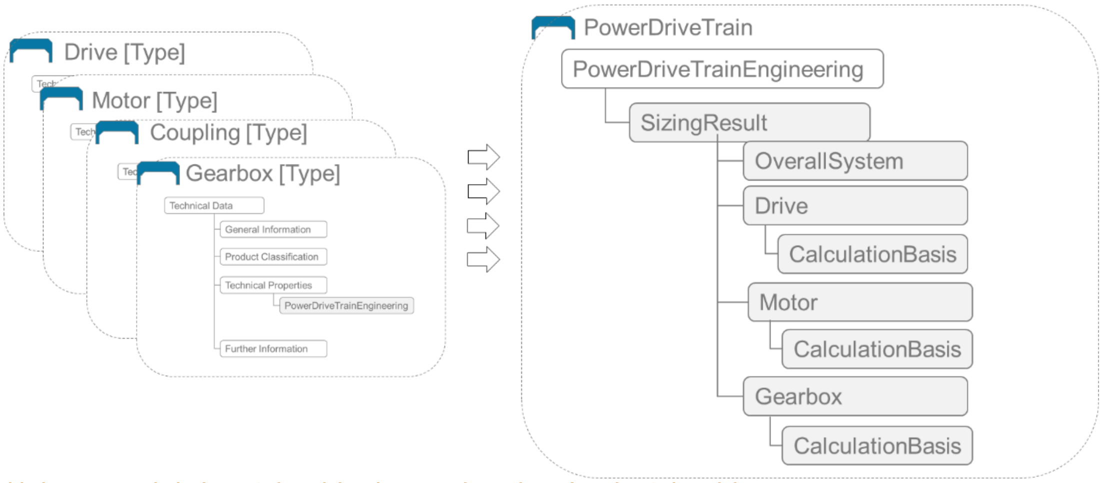

Figure 5 Relationship between TechnicalData Submodel and PowerDriveTrainEngineering Submodel

3 Further work and outlook

3.1 Practical application in the funded project Reallabor Antrieb 4.0

The joint research project "Reallabor Antrieb 4.0" pursues the overarching objective of creating a central basis for the development of service-oriented business models around digitized production and the networked value chain in a data space or ecosystem Drive 4.0. It is based on the ambitious goals of the ZVEI white paper "Drive 2030". The project is pursuing an innovative research and development approach to make the added value of drives of the future tangible for various stakeholder groups. In order to develop concrete new service scenarios, a catalog of requirements and an application roadmap will first be drawn up jointly with renowned associated industrial partners (who are involved with extensive contributions of their own). Current research activities from other projects, such as data management (GAIA-X) and collaborative condition monitoring, will also be taken into account.

3.2 Extended use case: sizing and simulation of energy consumption

Drive sizing is the basis for determining the energy supply of a machine according to demand. As a rule, a machine has several drives and consumers. Drives are often used very dynamically and can exchange energy, so that the power supply does not have to be designed for the sum of the maximum and continuous power. For example, to justify the use of energy-efficient technologies, such as “DC-Industrie”, energy storage or photovoltaic systems, it must be possible to recalculate the calculations from the drive sizing, possibly also for relevant load types for consumption estimations.

These application scenarios are needed throughout the entire life cycle at the machine builder and operator. Here is a short list of concrete scenarios.

- Development of a machine: Searching and finding the energy supply of a machine
- Distribution of a machine: Verification of the energy efficiency of a machine with regard to operator-specific operating modes
- Operation of a machine: Searching and finding energy-efficient replacement components

To solve these tasks, the machine builder and operator is dependent on the component supplier. The solution to this challenging task is the provision of calculation and simulation models, which can include the behavior of the components, e.g. for virtual commissioning, but also the calculations of the drive design.

With the possibilities of the asset administration shell, the generation of overall calculations and simulations of a machine for different use cases is thinkable in the perspective. Currently, IDTA is working on an information model for providing and requesting calculation and simulation models.

3.3 Registration of AAS Submodel template via IDTA

The aim of the IDTA registration of Asset Administration Shell templates for Digital Twins process is primarily to ensure that Submodels are correct in relation to the standardized meta model, describe a well-defined purpose and meet a certain quality standard. The ZVEI I4.0 working group has handed over the submodel, which was to be made available to public in advance in this discussion paper, in the IDTA process. The current status can be found at https://industrialdigitaltwin.org/en/content-hub/submodels "Engineering of Power Drive Trains".

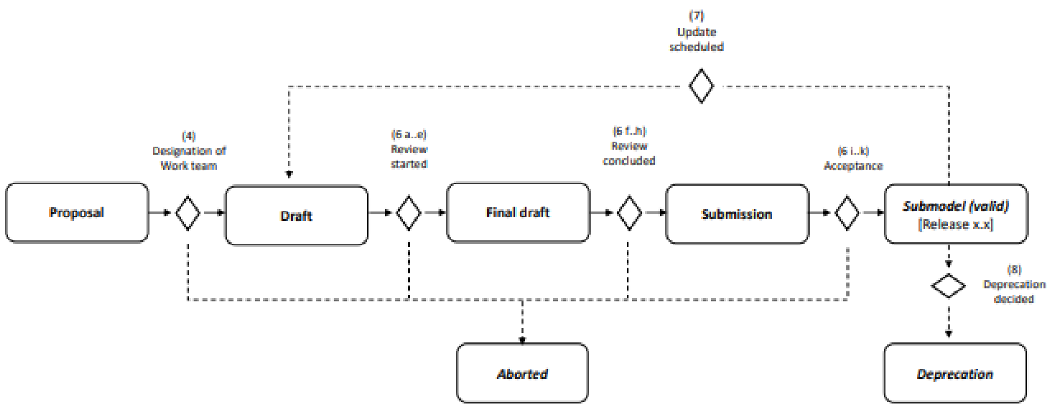

Figure 6 Life cycle of a IDTA Submodel project

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