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**M. BRADAC[1], F. ZOUHAR[1], J. KRIZAN[1], M. BLIZNAK[1], L. VARGOVCIK[1], O. KONONIKHYN[2], Y. PAVLYUK[3], Y. KRAVCHENKO[3]**

[1] ***UNIS, a.s., Czech Republic***
[2] ***PJSC "FED", Ukraine***
[3] ***State Enterprise "KhADB", Ukraine***

# MODEL BASED DESIGN APPLIED FOR DEVELOPMENT OF FUEL METERING PUMP CONTROL ALGORITHM

*A short review of the use of Model Based Design (MBD) in the development process of a fuel metering pump control algorithm with an ability to control the BE2 turbine engine is presented. The design and testing of the regulators and calibrations were performed using the Matlab®/Simulink® environment. The dSpace system was used to identify the FMP parameters, then for evaluating the designed control algorithms and finally for performance tests of the target platform. The results of this approach can be taken as a pattern for projects where it is necessary to save development time, testing costs, and fast changes of source code for target device are needed.*

***Key words:*** *Model based design, dSpace, fuel metering pump, code generation, simulation, Matlab, Simulink.*

## Introduction

The Model Based Design (MBD) method is a mathematical visualization method based on modelling the plant and control system with the opportunity to generate final code for the target platform. The MBD includes overall design of control with modelling, analysis, simulation and synthesis of control algorithms, with the ability to progressively test each sub-process of the design on the final platform.

As shown in Fig. 1, the MBD development process is composed of five main sub-processes:

− Analysis – description of required functionality, physical behaviour and target platform;

− Design – transformation of the requirements and physical behaviour into the simulated form for their validation and further usage;

− Implementation – transformation of the algorithms into compilable code for the target platform;

− Integration – compilation of the source code and its loading into the target platform;

− Test & Verification –verification of the development process outputs against requirements. This sub-process runs simultaneously with all other development processes.

In this paper, an analysis is provided of the problem of control algorithm design with minimal use of the target device and maximum time saving. The Project partners' relationship is shown in Fig. 2:

1. Developer and manufacturer of aviation aggregates and fuel control systems [5].
2. European Union project [7].
3. Developer of aerospace and advanced control [6].

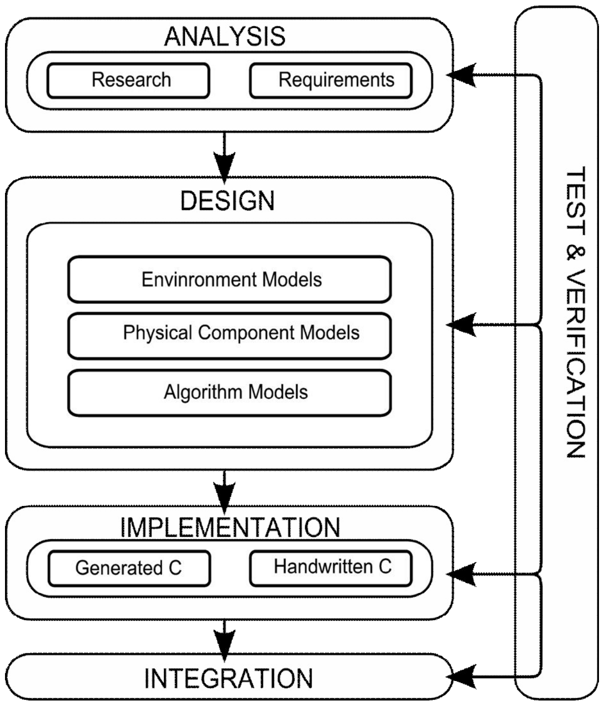


Fig. 1. MBD process

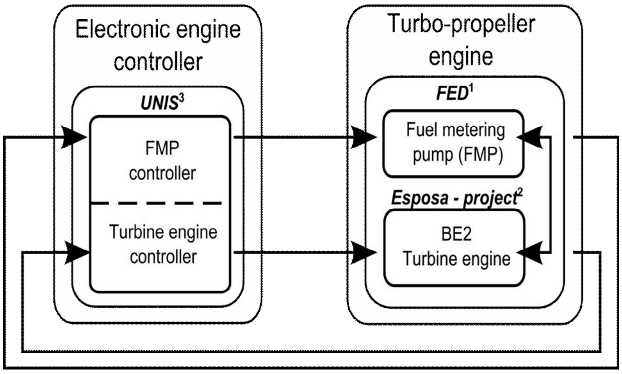


Fig. 2. Project partners' relationship

## 1. Analysis

The MBD method was applied on the Fuel Metering Pump (FMP) for a BE2 turbine engine [7]. The FMP is an electro-hydro-mechanical device with high precision setting of the fuel flow. The DC motor is used as actuator, and sensing of valve position is ensured by inductive position sensor.

For MBD the description of the FMP by differential equations was used. The MBD description by the differential equations was created according to the information defined in FMP specification (obtained from FMP producer) and performed experiments.

The objective of the MBD was to create the FMP control algorithm with an ability to control the BE2 turbine engine. The developed FMP control algorithm was combined with other algorithms to ensure the reliable and error-free functionality of the BE2 turbine engine and its accessories.

### 1.1. FMP identification

Identification of the FMP is based on the acquired data from two main information sources; characteristics measured on the real HW (FMP) and data acquired from simulations of the physical models. Characteristics of the real FMP device were obtained via dSpace equipment (chap. 3.1), which offered a high performance measuring interface. It allowed performance of detailed analysis of FMP parameters and behaviour.

During the FMP identification the reaction of the FMP to the various reference signals (ramp, stairs, saw, step, etc.) was observed. One of the main objectives of the FMP identification was exploration of the mechanical characteristics (friction, speed, and acceleration) and electrical parameters (currents).

The obtained data were used to tune the models of the FMP, thereby reflecting the behaviour of the real FMP (chap. 2.1).

## 2. Design

The design process composed of transforming the mathematical equations into models which can be used for simulations. These models may include algebraic equation, logical equations, differential equations (for continuous systems) and difference equations (for discrete systems). The process was divided into the following two phases:

- Design of model of fuel metering pump;
- Control algorithm design.

### 2.1. Design of model of fuel metering pump

The FMP model was created in the Matlab®/Simulink® environment. The model of the FMP physical components was created according to obtained description by the differential equations. Created models were tested and tuned using the obtained data from the FMP in the previous sub-process of MBD.

### 2.2. Control algorithm design

Based on the identification of the FMP behaviour a control algorithm was designed. The control algorithm was designed in the following three phases:

1. Design of continuous regulator.
2. Design of special discontinuous regulator.
3. Design of initial and on-line calibration of control algorithm.

The design of the special discontinuous regulator was a necessary step to eliminate the unpredictable influence of friction features which precluded the use of a continuous regulator.

The design and testing of the regulators and calibrations were performed off-line using the Matlab®/Simulink® environment. This method allows creating, testing and verifying the control algorithms without the necessity to use the real FMP HW, thereby reducing the development time.

The control algorithm simulation model was tested in wide range of conditions:

- Constant friction,
- Variable friction (continuous change),
- Variable friction (step change) ,
- Change of power supply.

Simulation results and test results of FMP behaviour are given in Fig.3, 4.

As it is shown in figures, the valve behaviour is very similar but additional peaks in simulation results have occoured. These peaks are caused by numerical errors in mathematical model of FMP.

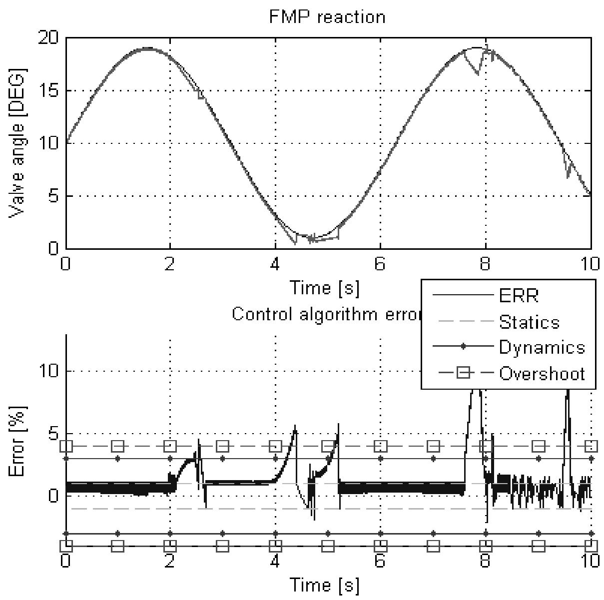


Fig. 3. FMP behaviour – simulation results

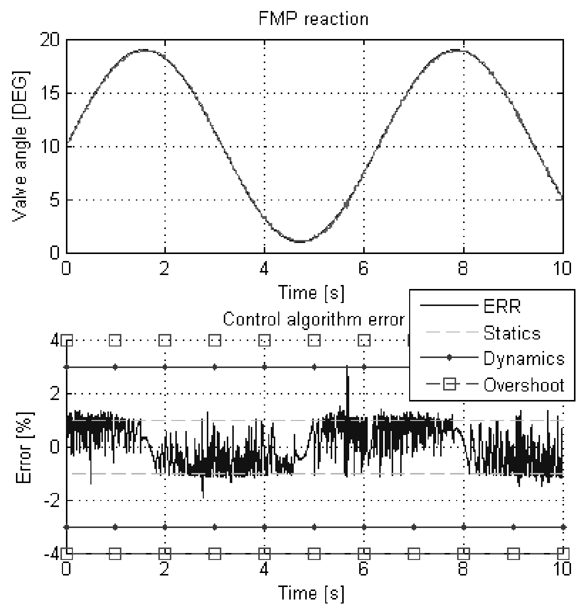


Fig. 4. Behaviour of real FMP

## 3. Implementation

During implementation, the control algorithm model is converted from Simulink model to the target platform source code in C language. The compiled target source code was tested against its defined requirements.

### 3.1. Use of dSpace developing tools

The dSpace is a set of developing tools with a variety of HW/SW tools for Rapid Control Prototyping and Hardware-in-the-loop tests. Typically, the real-time platform is programmed via automatically generated code from Matlab®/Simulink®. The modular system allows the use different processor boards, I/O boards and link boards. Thanks to these features this system can substitute either the FMP device or the Fuel metering pump electronics (FMPE)

### 3.2. Use of dSpace in the development process

Firstly, the dSpace system was used to identify the FMP parameters, then for evaluating the designed control algorithms and finally for performance tests of the target platform. Fig. 5 describes the stages of development from model through final implementation to target platform.

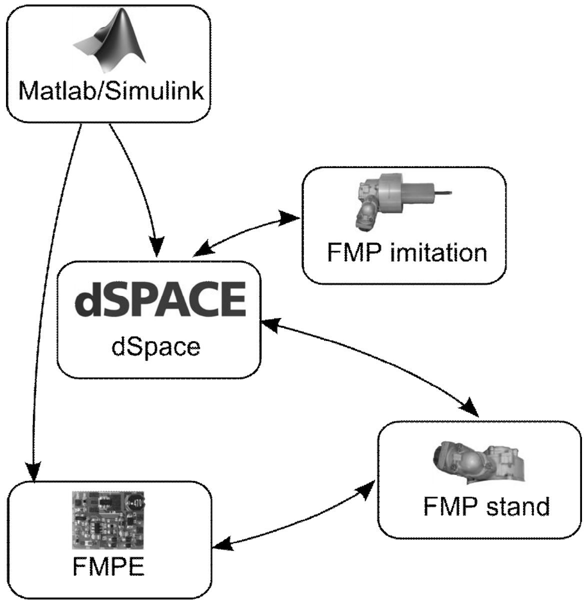


Fig. 5. Use of dSpace in the overall control algorithm development process

### 3.3. Code generation for target microcontroller

The main goal of using of the automatic code generation tools is to set up the development environment for rapid prototyping for fast changes in response to changing user requirements. In this environment the reusable libraries (Matlab Simulink model, C code algorithms) for different target platforms can be created.

The aim was not to generate complete code implementable to the final device, since the target platform low level services and functions were used from standard UNIS company C code library, but to generate higher-level code implementing control logic. The entire algorithm was separated into logical parts representing separate tasks and functions. Standard interface was developed to interface tasks and also the code from UNIS standard C code libraries.

The next phase of the development process is creation of the final control algorithm. The control algorithm was generated using the Simulink Coder. The Simulink Coder generated target C code from the verified control algorithm designed during the design sub-process.

### 3.4. Evaluating generated code

The control algorithm was modelled, tested against its requirements and automatically transformed into C code. This C code was validated by comparing outputs of the model with those of the generated code.

## 4. Integration

This process consists of integrating automatically generated C code from Simulink into the other modules. This final code is then compiled and uploaded to the target platform ready for testing and verification.

## 5. Test & Verification

The test and verification process was divided into the following two phases:

– Test of FMP control algorithm,
– Evaluation on real system.

### 5.1. Test of FMP control algorithm

The generated and compiled source code was loaded into the target FMPE dedicated to control of the FMP. The control electronics were composed of three sections:

1. Microcontroller unit (MCU) – implementation of the created SW.
2. Signal section – processing of input signals.
3. Power section – changing the voltage level for driving the motor and sensors.

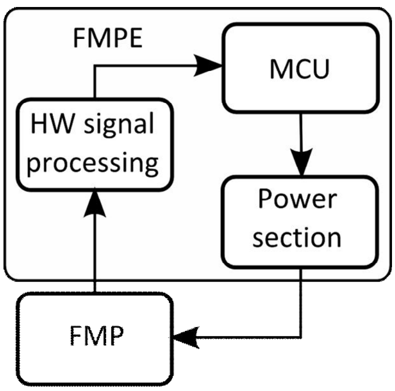


Fig. 6. Structure of FMPE

The correct function of FMPE with developed SW was tested in a loop with dSpace. The behaviour results were verified against the results of simulations.

In this configuration, dSpace represented the FMP. The FMP model was run inside dSpace and generated appropriate responses in reaction to FMPE intervention. At the end of this dSpace testing phase the FMPE with SW was ready for use on a real FMP.

### 5.2. Evaluation on real system

The last phase in the MBD process was testing of the control algorithm in FMPE on a real FMP. The FMPE in the configuration tested in the previous phase was connected to the real FMP (instead of dSpace) and performance was tested.

Initially evaluation was carried out with no environmental influence (no friction change, no fuel flow through pump and valve) and after that with environmental influence. Because of the MBD process major errors were eliminated in the previous phases, and so the time necessary to work on the real FMP was reduced to a minimum. This resulted in a reduction of development process costs.

## Conclusion

The Model Based Design and Rapid Control Prototyping development approach was applied on a real engineering task.

In the analysis sub-process the behaviour of the FMP friction, speed, and acceleration was examined.

During the design sub-process the simulation models of the FMP and control algorithm were created.

After implementation in the test and verification sub-process the models were tested in the phase intended to eliminate errors. The control algorithm was compiled into C code and after integration into standardized C code libraries implemented into FMPE.

The results were evaluated and the entire process was finished.

During the whole development process, a significant time-saving was observed.

## Acknowledgments

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**Рецензент:** Associate Professor R. Grepl, Brno University of Technology, Faculty of Mechanical Engineering, Institute of Solid Mechanics, Mechatronics and Biomechanics, Brno, Czech Republic.

### ПРИМЕНЕНИЕ МОДЕЛЬНО-ОРИЕНТИРОВАННОГО ПРОЕКТИРОВАНИЯ ДЛЯ РАЗРАБОТКИ АЛГОРИТМА УПРАВЛЕНИЯ НАСОСОМ-ДОЗАТОРОМ

***М. Брадач, Ф. Зухар, Й. Крыжан, М. Близнак, Л. Варговчик, А. Кононыхин, Е. Павлюк, Ю. Кравченко***

Представлен короткий обзор применения модельно-ориентированного проектирования (МОП) для разработки алгоритма управления насосом-дозатором для газотурбинного двигателя BE2. Разработка, тестирование и калибровка регуляторов выполнялись в среде Matlab®/Simulink®. Система dSpace использовалась для идентификации параметров модели насоса-дозатора, затем для оценки разработанных алгоритмов управления и функциональных испытаний управляющего устройства. Результаты применения метода могут бать использованы в качестве шаблона в тех проектах, где требуется минимизация затрат времени и средств, а также необходимо быстрое проведение изменений программного кода управляющего устройства.

**Ключевые слова:** модельно-ориентированное проектирование, dSpace, насос-дозатор, генерация кода, моделирование, Matlab, Simulink.

### ЗАСТОСУВАННЯ МОДЕЛЬНО-ОРІЄНТОВАНОГО ПРОЕКТУВАННЯ ДЛЯ РОЗРОБКИ АЛГОРИТМУ УПРАВЛІННЯ НАСОСОМ-ДОЗАТОРОМ

***М. Брадач, Ф. Зухар, Й. Крижан, М. Блізнак, Л. Варговчік, О. Кононихін, Є. Павлюк, Ю. Кравченко***

Представлений короткий огляд застосування модельно-орієнтованого проектування (МОП) для розробки алгоритму управління насосом-дозатором для газотурбінного двигуна BE2. Розробка, тестування і калібрування регуляторів виконувалися в середовищі Matlab®/Simulink®. Система dSpace використовувалася для ідентифікації параметрів моделі насоса-дозатора, потім для оцінки розроблених алгоритмів управління і функціональних випробувань керуючого пристрою. Результати застосування методу можуть бути використані в якості шаблону в тих проектах, де потрібна мінімізація витрат часу і коштів, а також необхідно швидке проведення змін програмного коду керуючого пристрою.

**Ключові слова:** модельно-орієнтоване проектування, dSpace, насос-дозатор, генерація коду, моделювання, Matlab, Simulink.

**Bradac Martin** – SW Development Specialist, UNIS a.s., Brno, Czech Republic, e-mail: mbradac@unis.cz.

**Zouhar Frantisek** – SW Development Specialist, UNIS a.s., Brno, Czech Republic, e-mail: fzouhar@unis.cz.

**Krizan Jakub** – SW Development Specialist, UNIS a.s., Brno, Czech Republic, e-mail: jkrizan@unis.cz.

**Bliznak Michal**– SW Development Specialist, UNIS a.s., Brno, Czech Republic, e-mail: mbliznak@unis.cz.

**Vargovcik Lubos** – Analyst for Control and Information System, UNIS a.s., Brno, Czech Republic, e-mail: vargovcik@unis.cz.

**Kononikhyn Oleksandr** – Deputy Chairman of the Board, PJSC "FED", Kharkiv, Ukraine, e-mail: avk@fed.com.ua.

**Pavlyuk Yevgen -** First Deputy Director, candidate of science, SE "KhADB", Kharkiv, Ukraine, e-mail: pav_ev@ukr.net.

**Kravchenko Yurij** - Deputy Chief Designer, SE "KhADB", Kharkiv, Ukraine, e-mail: khadb_ykr@ukr.net.