

## REFERENCES

- [1] Ahlberg JH, Nilson EN and Walsh JL (1967) *The Theory of Splines and Their Applications*. Academic Press, Mathematics in Science and Engineering, New York and London
- [2] Aldhaferi RW (1991) Model reduction via Shur-form decomposition. *Int.J. Control* 53: 709-716
- [3] Allemandou P (1966) Low-pass filters approximating - in modulus and phase - the exponential function. *IEEE Transactions on Circuit Theory* 13: 298-301,
- [4] Al-Saggaf UM, Franklin GE (1988) Model Reduction Via Balanced Realizations: An Extension and Frequency Weighting Techniques. *IEEE Trans. Autom. Control* 33: 687-691
- [5] Arumugam M, Ramamoorthy M. (1973) A method of simplifying large dynamic systems. *Int. J. Control* 17: 1129-1135
- [6] Barnett S (1973) New reductions of Hurwitz determinants. *Int. J. Control* 18: 977-991
- [7] Bendat JS, Piersol AG (1976) *Metody analizy i pomiaru sygnalow losowych*. PWN, Warszawa
- [8] Birch BJ, Jackson R (1959) The behaviour of linear systems with inputs satisfying certain bounding conditions. *J. Electronics and Control* 6: 366-375
- [9] Bosley MJ, Kropholler HW and Lees FP (1973) On the relation between the continued fraction expansion and moments matching methods of model reduction. *Int. J. Control* 18: 461-474
- [10] Burden RL, Faires JD (1985) *Numerical Analysis*. PWS-KENT Publishing Company, Boston
- [11] Candy JV (1988) *Signal Processing. The Modern Approach*. McGraw-Hill Book Company, New York
- [12] Chen CF, Chu H (1966) A Matrix for Evaluating Schwarz's Form. *IEEE Trans. Autom. Control* 4: 303-305,
- [13] Chen CF, Shieh LS (1968) A novel approach to linear model simplification. *Int. J. Control* 8: 561-570
- [14] Ching-Tien L, Yi-Shyong C (1988) Successive parameter estimation of continuous dynamic systems. *Int. J. Systems Science* 19: 1149-1158
- [15] Davison E J (1966) A Method for Simplification Linear Dynamic Systems. *IEEE Trans. Autom. Control* 11: 93-101
- [16] Director SW, Rother RA (1972) *Introduction To Systems Theory*. McGraw-Hill, New York
- [17] Eykhoff P (1974) *System Identification. Parameter and State Estimation*. John Wiley and Sons. London
- [18] Fhrumann A (1996) *A Polynomial Approach to Linear Algebra*. Springer-Verlag, New York
- [19] Friedland B (1989) On the Properties of Reduced-Order Kalman Filters. *IEEE Trans. Autom. Control* 34: 321-324
- [20] Fuksa S, Byrski W (1980) Problem optymalizacji pewnego typu funkcjonalow kwadratowych na zbiorach wypuklych. *Prace VIII Krajowej Konferencji Automatyki*. Szczecin: 62-64

- 
- [21] Gajda J, Szyper M. (1998) Modelowanie i badania symulacyjne systemow pomiarowych. Jartek s.c. Krakow
- [22] Gawransky W, Natke HG (1988) Order estimation of AR and APMA models. *Int. J. Systems Science* 19: 1143-1148
- [23] Goldberg DE (1989) Genetic Algorithms in Search, Optimization, and Machine Learning. Addison-Wesley Publishing Company, USA
- [24] Gutman P, Mannerfelt F and Molamder P (1982) Contribution to the Model Reduction Problem. *IEEE Trans. Autom. Control* 27: 454-455,
- [25] Hagel R, Zakrzewski J (1984) Miernictwo dynamiczne. WNT, Warszawa
- [26] Halevi Y (1996) Reduced order models with delay. *Int. J. Control* 64: 733-744,
- [27] Helavi Y (1992) Frequency Weighted Model Reduction via Optimal Projection. *IEEE Trans. Autom. Control* 37: 1537-1542
- [28] Hutton MF, Friedland B (1975) Routh approximations for reducing order of linear time-invariant systems. *IEEE Trans. Autom. Control* 20: 329-337
- [29] Hwang C, Lee Y (1989) Multifrequency Padé Approximation Via Jordan Continued-Fraction Expansion. *IEEE Trans. Autom. Control* 34: 444-446
- [30] Johnson CD, Wonham WM (1966) Another Note on the Transformation to Canonical (Phase-Variable) Form. *IEEE Trans. on Autom. Control*. 7: 609-610
- [31] Kaczorek T (1996) Teoria sterowania i systemow. PWN, Warszawa
- [32] Kong SY, Lin DW (1981) Optimal Henkel Norm Model Reductions: Multivariable Systems. *IEEE Trans. Autom. Control* 26: 832-852
- [33] Kordylewski W, Wach J (1988) Usrednione rozniczkowanie zakloconych sygnalow pomiarowych. *PAK* 6: 123-124
- [34] Krishnamurthy V, Seshadri V (1976) A simple and direct method of reducing the order of linear, time-invariant systems by Routh approximation frequency domain. *IEEE Trans. Autom. Control*. 20: 797-799
- [35] Krishnamurthy V, Seshadri V (1978) Model Reduction Using the Routh Stability Criterion. *IEEE Trans. Autom. Control* 23: 729-731
- [36] Ku YH (1961) Transient Circuit Analysis. D. Van Nostrand Co. Inc., Princeton
- [37] Lam J (1993) Model reduction of delay systems using Padé approximation. *Int. J. Control* 57: 377-391
- [38] Lam J, Yang G (1996) Balanced model reduction of symmetric composite systems. *Int. J. Control* 65: 1031-1043,
- [39] Lamba S, Goerz R and Bandyopadhyay B (1988) New reduction technique by step error minimization for multivariable systems. *Int. J. Systems Science* 19: 999-1009
- [40] Layer E (1981) Theoretical foundations of the calibration process of measuring systems in the aspect of dynamic errors. *Proc. IMEKO Symposium on Computerized Measurement, Dubrovnik*: 113-116
- [41] Layer E (1981) Podstawy teorii wzorcowania systemow pomiarowych w aspekcie bledow dynamicznych. ZN AGH, Krakow
- [42] Layer E (1982) Basic problems of the calibration process and of the establishing a hierarchy of accuracy for dynamic measuring systems. *Proc. IMEKO 9<sup>th</sup> World Congress, Berlin (West)* 5/3: 269-277
- [43] Layer E (1997) Theoretical Principles for Establishing a Hierarchy of Dynamic Accuracy with the Integral-Square-Error as an Example. *IEEE Trans. Instrumentation and Measurement* 46: 1178-182

- 
- [44] Layer E (1999) Mapping Error of Simplified Dynamic Models in Electrical Metrology. Proc. 16<sup>th</sup> IEEE Instrumentation and Measurement Technology Conference, Venice 3: 1704-1709
- [45] Layer E (2001) Mapping Error of Linear Dynamic Systems Caused by Reduced-Order Model. IEEE Trans. Instrumentation and Measurement 50: 792-800
- [46] Layer E (2001) Przestrzen rozwiazan sygnalow maksymalizujacych kwadratowy wskaznik jakosci. Mat. Konf. Modelowanie i symulacja systemow pomiarowych. AGH, Krynica: 25-28
- [47] Layer E, Gawedzki W (1991) Dynamika aparatury pomiarowej. Badania i ocena. PWN, Warszawa
- [48] Layer E, Gawedzki W (1993) Time frequency properties of signals maximizing the dynamic errors. Systems-Analysis-Modelling-Simulation, Gordon & Breach Science Publisher 11: 73-77,
- [49] Layer E, Piwowarczyk T (1999) Application of the generalized Fibonacci sequences to the simplification of mathematical models of linear dynamic systems. Archives of Electrical Engineering. Polish Scientific Publishers PWN, Warsaw 187/188: 19-30
- [50] Layer E, Piwowarczyk T (2000) Generalised Fibonacci Series in the Description of Dynamic Models. Systems-Analysis-Modelling-Simulation, Gordon & Breach Science Publisher 37: 57-67
- [51] Leitner R (1995) Zarys matematyki wyzszej. WNT, Warszawa
- [52] Ljubojevic M (1973) Suboptimal input signal for linear system identification. Int. J. Control 17: 659-669
- [53] Luenberger DG (1967) Canonical forms for linear multivariable systems. IEEE Trans. Autom. Control 12: 290-293
- [54] Luke YL (1969) The Special Functions and their Approximations. Academic Press, New York
- [55] Luke YL (1975) Mathematical Functions and their Approximations. Academic Press, New York,
- [56] Marczuk GI (1983) Analiza numeryczna zagadnien fizyki matematycznej. PWN Warszawa
- [57] Meier L, Luenberger DG (1967) Approximation of linear constant systems. IEEE Trans. Autom. Control 12: 585-588
- [58] Moore BC (1981) Principal Component Analysis in Linear Systems: Controllability, Observability, and Model Reduction. IEEE Trans. Autom. Control 26: 17-31,
- [59] Noble B, Daniel JW (1997) Applied Linear Algebra. Prentice-Hall Inc. Englewood Cliffs, New Jersey
- [60] Orlowski M. (1992) Odtwarzanie usrednionych sygnalow wejsciowych na podstawie zaszumionych sygnalow wyjsciowych. Ph.D Thesis, Politechnika Szczecinska, Szczecin
- [61] Pernebo L, Silverman LM (1982) Model reduction via balanced-truncation model reduction. IEEE Trans. Autom. Control 27: 382-387
- [62] Piotrowski J, Kostyrko K (2000) Wzorcowanie aparatury pomiarowej. PWN Warszawa
- [63] Piwowarczyk T (1996) Coefficients of power expansion of original as function of transform coefficients. Cracow University of Technology, Czasopismo Techniczne, 93/7 E: 21-30

- 
- [64] Piwowarczyk T (2000) Multipower Notation of Symmetric Polynomials in Engineering Calculus. Wydawnictwo Instytutu Gospodarki Surowcami Mineralnymi i Energia PAN, Krakow
- [65] Rane DS (1996) A Simple Transformation to (Phase-Variable) Canonical Form. IEEE Trans. Autom. Control 7: 608
- [66] Rao S.A., Lamba SS (1974) A new frequency domain technique for the simplification of linear dynamic systems. Int. J. Control 20: 71-79
- [67] Rutland NK (1994) The Principle of Matching: Practical Conditions for Systems with Inputs Restricted in Magnitude and Rate of Change. IEEE Trans. Autom. Control 39: 550-553
- [68] Safonov MG, Chiang RY (1989) A Schur Method for Balanced-Truncation Model Reduction". IEEE Trans. Autom. Control 34/7: 729-733
- [69] Sarma IG, Pai MA and Viswanathan R (1968) On the Transformation to Schwarz Canonical Form. IEEE Trans. Autom. Control 6: 311-312
- [70] Shamash Y (1975) Model reduction using Routh stability criterion and the Pade approximation technique. Int. J. Control 21: 475-484
- [71] Sinha NK, Bereznaï GT (1971) Optimum approximation of high-order systems by low order model. Int. J. Control 21: 951-959
- [72] Sinha NK, De Bruin H (1973) Near optimal control of high-order systems using low-order models. Int. J. Control 17: 257-262
- [73] Sinha NK, Pille W (1971) A new method for reduction of dynamic systems. Int. J. Control 14: 111-118
- [74] Skoczowski S (1995) Identyfikacja praktyczna modeli transmitancyjnych na podstawie początkowej fazy odpowiedzi skokowej. Kwartalnik Elektroniki i Telekomunikacji 41: 5-29
- [75] Tietze U, Schenk C (1974) Halbleiter- Schaltungstechnik. Springer-Verlag, Berlin
- [76] Tsu-Tian L, Shuh-Chuan T (1988) Solution of linear dynamic systems with initial or boundary value conditions by shifted Chebyshev approximations. Int. J. Systems Sciences 19: 1225-1234
- [77] Tuel WG Jr. (1966) On the Transformation to (Phase-Variable) Canonical Form. IEEE Trans. Autom. Control 7: 607
- [78] Whitefield AH, Williams NG (1988) Integral least-squares techniques for frequency-domain model reduction. Int. J. Systems Science 19: 1355-1373
- [79] Wilson DA (1974) Optimum solution of model reduction problem. Int. J. Control 20: 57-64
- [80] Yasuyuki F, Kaheu N (1973) Identification of discrete-time systems using a composite sinusoidal signal. Int. J. Control 18: 945-962
- [81] Zakian V (1973) Simplification of linear time-invariant systems by moment approximants. Int. J. Control 18: 455-460
- [82] Zakian V (1989) Critical systems and tolerable inputs. Int. J. Control 49: 1285-1289
- [83] Zakian V (1996) Perspectives of the principle of matching and the method of inequalities. Int. J. Control 65: 147-175
- [84] Zill DG (1986) Differential Equations with Boundry-Value Problems. Prindle, Weber & Schmidt, Boston
- [85] Zakowski W, Leksinski W (1995) Matematyka, Czesc IV. WNT, Warszawa
- [86] Zuchowski A (1998) Uproszczone modele dynamiki. Politechnika Szczecińska, Instytut Automatyki Przemysłowej, Szczecin

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