

EXISTENCE OF THREE WEAK SOLUTIONS FOR KIRCHHOFF-TYPE PROBLEMS WITH VARIABLE EXPONENT AND NONHOMOGENEOUS NEUMANN CONDITIONS

S. HEIDARKHANI*, A.L.A. DE ARAUJO**, G.A. AFROUZI*** AND S. MORADI***

*Department of Mathematics, Faculty of Sciences, Razi University, 67149 Kermanshah, Iran
E-mail: s.heidarkhani@razi.ac.ir

**Departamento de Matemática, Universidade Federal de Viçosa, 36570-000, Viçosa (MG), Brazil
E-mail: anderson.araujo@ufv.br

***Department of Mathematics, Faculty of Mathematical Sciences, University of Mazandaran,
Babolsar, Iran
E-mail: afrouzi@umz.ac.ir, shahin.moradi86@yahoo.com

Abstract. We study the existence of at least three weak solutions for a class of differential equations with $p(x)$ -Kirchhoff-type and subject to perturbations of nonhomogeneous Neumann conditions. Our technical approach is based on variational methods. Some applications and examples illustrate the obtained results.

Key Words and Phrases: Variable exponent Sobolev spaces, $p(x)$ -Kirchhoff-type problems, three weak solutions, variational methods.

2010 Mathematics Subject Classification: 35J20, 35J60, 47H10.

REFERENCES

- [1] G.A. Afrouzi, A. Hadjian, S. Heidarkhani, *Steklov problem involving the $p(x)$ -Laplacian*, Electronic J. Differ. Equ., **2014**(2014), no. 134, 1-11.
- [2] S.N. Antontsev, J.F. Rodrigues, *On stationary thermo-rheological viscous flows*, Ann. Univ. Ferrara Sez. VII Sci. Mat., **52**(2006), 19-36.
- [3] S.N. Antontsev, S.I. Shmarev, *A model porous medium equation with variable exponent of nonlinearity: existence, uniqueness and localization properties of solutions*, Nonlinear Anal. TMA, **60**(2005), 515-545.
- [4] G. Autuori, F. Colasuonno, P. Pucci, *Blow up at infinity of solutions of polyharmonic Kirchhoff systems*, Complex Var. Elliptic Eqs., **57**(2012), 379-395.
- [5] G. Autuori, F. Colasuonno, P. Pucci, *Lifespan estimates for solutions of polyharmonic Kirchhoff systems*, Math. Mod. Meth. Appl. Sci., **22**(2012), 1150009 [36 pages].
- [6] G. Autuori, F. Colasuonno, P. Pucci, *On the existence of stationary solutions for higher-order p -Kirchhoff problems*, Commun. Contemp. Math., **16**(2014), 1450002 [43 pages].
- [7] D. Averna, G. Bonanno, *Three solutions for a Neumann boundary value problem involving the p -Laplacian*, Le Matematiche, **60**(2006), 81-91.
- [8] G. Bonanno, P. Candito, *Non-differentiable functionals and applications to elliptic problems with discontinuous nonlinearities*, J. Differ. Equ., **244**(2008), 3031-3059.

- [9] G. Bonanno, P. Candito, *Three solutions to a Neumann problem for elliptic equations involving the p -Laplacian*, Arch. Math. (Basel), **80**(2003), 424-429.
- [10] G. Bonanno, A. Chinni, *Existence and multiplicity of weak solutions for elliptic Dirichlet problems with variable exponent*, J. Math. Anal. Appl., **418**(2014), 812-827.
- [11] G. Bonanno, A. Chinni, *Multiple solutions for elliptic problems involving the $p(x)$ -Laplacian*, Le Matematiche, **LXVI**(2011), Fasc. I, 105-113.
- [12] G. Bonanno, G. D'Agui, *Multiplicity results for a perturbed elliptic Neumann problem*, Abstr. Appl. Anal., **2010**(2010), DOI: 10.1155/2010/564363, 10 pages.
- [13] G. Bonanno, S.A. Marano, *On the structure of the critical set of non-differentiable functions with a weak compactness condition*, Appl. Anal., **89**(2010), 1-10.
- [14] F. Cammaroto, A. Chinni, B. Di Bella, *Multiple solutions for a Neumann problem involving the $p(x)$ -Laplacian*, Nonlinear Anal. TMA, **71**(2009), 4486-4492.
- [15] F. Cammaroto, L. Vilasi, *Existence of three solutions for a degenerate Kirchhoff-type transmission problem*, Num. Func. Anal. Opt., **35**(2014), 911-931.
- [16] F. Cammaroto, L. Vilasi, *Multiple solutions for a Kirchhoff-type problem involving the $p(x)$ -Laplacian operator*, Nonlinear Anal. TMA, **74**(2011), 1841-1852.
- [17] Y. Chen, S. Levine, M. Rao, *Variable exponent, linear growth functionals in image restoration*, SIAM J. Appl. Math., **66**(2006), 1383-1406.
- [18] N.T. Chung, *Multiplicity results for a class of $p(x)$ -Kirchhoff type equations with combined nonlinearities*, Electronic J. Qual. Theory Differ. Equ., **2012**(2012), 1-13.
- [19] F. Colasuonno, P. Pucci, *Multiplicity of solutions for $p(x)$ -polyharmonic elliptic Kirchhoff equations*, Nonlinear Anal. TMA, **74**(2011), 5962-5974.
- [20] G. D'Agui, S. Heidarkhani, G. Molica Bisci, *Multiple solutions for a perturbed mixed boundary value problem involving the one-dimensional p -Laplacian*, Electronic J. Qual. Theory Differ. Equ., **24**(2013), 1-14.
- [21] G. D'Agui, A. Sciammetta, *Infinitely many solutions to elliptic problems with variable exponent and nonhomogeneous Neumann conditions*, Nonlinear Anal. TMA, **75**(2012), 5612-5619.
- [22] G. Dai, R. Hao, *Existence of solutions for a $p(x)$ -Kirchhoff-type equation*, J. Math. Anal. Appl., **359**(2009), 275-284.
- [23] G. Dai, J. Wei, *Infinitely many non-negative solutions for a $p(x)$ -Kirchhoff-type problem with Dirichlet boundary condition*, Nonlinear Anal. TMA, **73**(2010), 3420-3430.
- [24] A.L.A. De Araujo, S. Heidarkhani, G.A. Afrouzi, S. Moradi, *A variational approach for nonlocal problems with variable exponent and nonhomogeneous Neumann conditions*, preprint.
- [25] A.L.A. De Araujo, S. Heidarkhani, G. Caristi, A. Salari, *Multiplicity results for nonlocal problems with variable exponent and nonhomogeneous Neumann conditions*, preprint.
- [26] S.G. Deng, *A local mountain pass theorem and applications to a double perturbed $p(x)$ -Laplacian equations*, Appl. Math. Comput., **211**(2009), 234-241.
- [27] X.L. Fan, *On nonlocal $p(x)$ -Laplacian Dirichlet problems*, Nonlinear Anal. TMA, **72**(2010), 3314-3323.
- [28] X.L. Fan, C. Ji, *Existence of infinitely many solutions for a Neumann problem involving the $p(x)$ -Laplacian*, J. Math. Anal. Appl., **334**(2007), 248-260.
- [29] X.L. Fan, D. Zhao, *On the spaces $L^{p(x)}(\Omega)$ and $W^{m,p(x)}(\Omega)$* , J. Math. Anal. Appl., **263**(2001) 424-446.
- [30] J.R. Graef, S. Heidarkhani, L. Kong, *A variational approach to a Kirchhoff-type problem involving two parameters*, Results Math., **63**(2013), 877-889.
- [31] T.C. Halsey, *Electrorheological fluids*, Science, **258**(1992), 761-766.
- [32] P. Harjulehto, P. Hästö, *An overview of variable exponent Lebesgue and Sobolev spaces*, in: D. Herron (Ed.), Future Trends in Geometric Function Theory, RNC Workshop, Jyväskylä, 2003, 85-93.
- [33] S. Heidarkhani, G.A. Afrouzi, A. Hadjian, *Multiplicity results for elliptic problems with variable exponent and nonhomogeneous Neumann conditions*, Math. Meth. Appl. Sci., **38**(2015), 2589-2599.

- [34] S. Heidarkhani, A.L.A. De Araujo, G.A. Afrouzi, S. Moradi, *Multiple solutions for Kirchhoff-type problems with variable exponent and nonhomogeneous Neumann conditions*, Math. Nach., **291**(2018), 326-342.
- [35] M. Hssini, M. Massar, N. Tsouli, *Existence and multiplicity of solutions for a $p(x)$ -Kirchhoff type problems*, Bol. Soc. Paran. Mat., **33**(2015), 201-215.
- [36] E.M. Hssini, N. Tsouli, M. Haddaoui, *Existence and multiplicity solutions for a $(p(x), q(x))$ -Kirchhoff type systems*, Le Matematiche, **LXXI**(2016), Fasc. I, 75-88.
- [37] G. Kirchhoff, *Vorlesungen uber Mathematische Physik: Mechanik*, Teubner, Leipzig, 1883.
- [38] O. Kováčik, J. Rákosník, *On the spaces $L^{p(x)}(\Omega)$ and $W^{1,p(x)}(\Omega)$* , Czechoslovak Math., **41**(1991), 592-618.
- [39] J.L. Lions, *On some questions in boundary value problems of mathematical physics*, In: Contemporary Developments in Continuum Mechanics and Partial Differential Equations (Proc. Internat. Sympos. Inst. Mat. Univ. Fed. Rio de Janeiro, 1977), North-Holland Math. Stud., **30**(1978), 284-346.
- [40] M. Massar, M. Talbi, N. Tsouli, *Multiple solutions for nonlocal system of $(p(x), q(x))$ -Kirchhoff type*, Appl. Math. Comput., **242**(2014), 216-226.
- [41] M. Mihăilescu, *Existence and multiplicity of solutions for a Neumann problem involving the $p(x)$ -Laplacian operator*, Nonlinear Anal. TMA, **67**(2007), 1419-1425.
- [42] G. Molica Bisci, V. Rădulescu, *Applications of local linking to nonlocal Neumann problems*, Commun. Contemp. Math., **17**(2014), 1450001 [17 pages].
- [43] G. Molica Bisci, V. Rădulescu, *Mountain pass solutions for nonlocal equations*, Annales AcademiæScientiarum FennicæMathematica, **39**(2014), 579-59.
- [44] G. Molica Bisci, V. Rădulescu, R. Servadei, *Variational Methods for Nonlocal Fractional Problems*, Encyclopedia of Mathematics and its Applications, vol. 162, Cambridge University Press, Cambridge, 2016.
- [45] D.S. Moschetto, *A quasilinear Neumann problem involving the $p(x)$ -Laplacian*, Nonlinear Anal. TMA, **71**(2009), 2739-2743.
- [46] C. Pfeiffer, C. Mavroidis, Y. Bar-Cohen, B. Dolgin, *Electrorheological fluid based force feedback device*, in: Proceedings of the 1999 SPIE Telemanipulator and Telepresence Technologies VI Conference (Boston, MA), **3840**(1999), 88-99.
- [47] C. Qian, Z. Shen, M. Yang, *Existence of solutions for $p(x)$ -Laplacian nonhomogeneous Neumann problems with indefinite weight*, Nonlinear Anal. RWA, **11**(2010), 446-458.
- [48] V. Rădulescu, *Nonlinear elliptic equations with variable exponent: old and new*, Nonlinear Anal. TMA, **121**(2015), 336-369.
- [49] V. Rădulescu, D. Repovš, *Partial Differential Equations with Variable Exponents, Variational Methods and Qualitative Analysis, Monographs and Research Notes in Mathematics*, CRC Press, Boca Raton, FL, 2015.
- [50] D. Repovš, *Stationary waves of Schrödinger-type equations with variable exponent*, Anal. Appl., **13**(2015), 645-661.
- [51] B. Ricceri, *On an elliptic Kirchhoff-type problem depending on two parameters*, J. Global Optim., **46**(2010), 543-549.
- [52] M. Ružička, *Electro-rheological Fluids: Modeling and Mathematical Theory*, Lecture Notes in Math., 1784, Springer, Berlin, 2000.
- [53] S. Samko, *On a progress in the theory of Lebesgue spaces with variable exponent maximal and singular operators*, Integral Transforms Spec. Funct., **16**(2005), 461-482.
- [54] Z. Shen, C. Qian, *Infinitely many solutions for a Kirchhoff-type problem with non-standard growth and indefinite weight*, Z. Angew. Math. Phys., **66**(2015), 399-415.
- [55] J. Simon, *Régularité de la solution d'une équation non linéaire dans \mathbb{R}^N* , Lecture Notes in Math. Springer, Berlin, Heidelberg, **665**(1978), 205-227.
- [56] L. Vilasi, *Eigenvalue estimates for stationary $p(x)$ -Kirchhoff problems*, Electronic J. Differ. Equ., **2016**(2016), no. 186, 1-9.
- [57] E. Zeidler, *Nonlinear Functional Analysis and its Applications*, II/B, Springer-Verlag, New York, 1990.

- [58] V.V. Zhikov, *Averaging of functionals of the calculus of variations and elasticity theory*, Math. USSR Izv., **9**(1987), 33-66.

Received: April 14, 2018; Accepted: September 6, 2018.

